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Report of the Working Group on Recruitment Forecasting in a Variable Environment (WGRFE)

13–17 June 2016

Ispra, Italy

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

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Contents

Executive summary

The Working Group on Recruitment Forecasting in a Variable Environment (WGRFE) held its initial meeting in Copenhagen, Denmark, 16–20 June 2014. At this meeting, four projects were defined: i) a study examining the impact of recruitment autocorrelation on forecast performance; ii) developing a statistical framework for modelling multi-stage recruitment functions (Paulik diagrams); iii) a review of literature incorporating environmental drivers in forecasts, focusing on whether forecasts were improved or not; and iv) developing a framework for performing ensemble forecasts, identifying case studies and illustrating the approach.

The WGRFE held its second meeting in Seattle, Washington, USA, 22–26 June 2015. At this meeting, results from the first two projects (recruitment autocorrelation, and multi-stage recruitment functions) were presented, and the group planned follow-up analyses to be conducted before the meeting in 2016. Work was also assigned to WG members towards the third project (review manuscript), and discussions on forecast ensembles were initiated, identifying a case study for haddock in the NW Atlantic Ocean.

WGRFE held its third meeting at the Joint Research Center in Ispra, Italy, 13–17 June 2016. With active participation from regular WGRFE members and JRC scientists, the WG explored the issues of assessment model averaging and multiple model forecasts, focusing specifically on statistical and software frameworks, updating of model weights based on performance, and approaches to defining the set of candidate models. A comprehensive case study on assessment modelling was presented. A simple ensemble forecast case study was presented, and a more complex case study was defined for further exploration at the next WG meeting. In addition, the WG focused on producing text for sections of a review manuscript of published articles that included environmental drivers in forecasts. Final results were presented on incorporating recruitment autocorrelation in forecasts, which suggest that autocorrelation can be estimated fairly well from assessment estimates of recruitment deviations and that including autocorrelation typically improved forecast performance, particularly for cases with informative data. This project resulted in a published manuscript (Johnson *et al.*, 2016). Final simulations were also defined for the multi-stage recruitment/Paulik diagram project. Manuscripts for the review paper on forecasting with environmental drivers and the Paulik diagram project are planned for submission in the fall of 2016. Work is expected to continue on the forecast ensemble project, with a meeting planned to be held in June 2017 in Woods Hole, MA (USA).

1 Administrative details

Working Group name

Working Group on Recruitment Forecasting in a Variable Environment (WGRFE)

Year of Appointment

2014

Reporting year within current cycle (1, 2 or 3)

3

Chair(s)

Samuel Subbey, Norway

Elizabeth Brooks, USA

Meeting venue(s) and dates

16–20 June 2014, Copenhagen, Denmark (14)

22–26 June 2015, Seattle, USA (13)

13–17 June 2016, JRC-Ispra, Italy (13)

2 Terms of Reference a) – z)

a (Year 1)	Review approaches (modelling and methodologies) where stock recruitment models incorporate external drivers, along with all caveats. Identify and collate datasets for use in ToR (b).
b (Year 2)	Develop prototype, statistical recruitment tools for selected stocks, based on stage-structured models which include environmental drivers and multispecies considerations
c (Year 3)	Testing, validation and documentation of prototype models.

3 Summary of Work plan

Year 1	Review state-of-the-art and caveats in developing recruitment forecasting models with environmental drivers
Year 2	Development of prototype, stage-structured models for recruitment forecasting for selected ices stocks
Year 3	Testing, validation and documentation of models and methodologies for peer review

4 Summary of Achievements of the WG during 3-year term

Summary— Year 1

- Reviewed approaches (modelling and methodologies) where stock recruitment models incorporate external drivers;
- Identified caveats associated with identifying environmental drivers and relating them to recruitment;
- Identified key datasets for future use
    - Baltic Cod, Sprat, Northeast Arctic Cod, North Sea Autumn Spawning Herring, North Sea Spring Spawning Herring, and Walleye Pollock.

Summary— Year 2

- Forecasting recruitment
    - Reviewed methods that are being used for recruitment forecasting in fisheries settings for broadly different stocks and areas;
    - Surveyed methods that perform well and might be considered as guidelines for applications to fisheries management and assessments;
    - Reviewed approaches to ensemble methods focusing on those that improve forecast accuracy or precision.
- Incorporating environmental drivers in forecasts
    - Literature review of 60+ papers, as basis for a draft manuscript
- Paulik diagrams
    - Simulation runs in a state-space framework for estimating a mulit-stage stock recruitment model. The program is coded in R and RJAGS. Case study for North Sea Autumn Spawning Herring
- Autocorrelated recruitment
    - Investigated the forecast performance of Stock Synthesis with autocorrelated recruitment deviations. Troubleshooting and follow-up analyses planned.

Summary—Year 3

- Final results presented for autocorrelated recruitment project; manuscript published: Johnson, K.F., E. Councill, J.T. Thorson, E.N. Brooks, R.D. Methot, A.E. Punt. 2016. Can autocorrelation be estimated using integrated assessment models and how does it affect population forecasts? Fisheries Research 183:222-232.
- Final specifications defined for simulation study of Paulik diagrams; manuscript Introduction and Methods secions are drafted. Submission planned fall 2016.
- Paper submitted to Journal of Mathematical Biology on 'Emergent properties of a multi-stage population dynamic model', Ute A. Schaarschmidt; Sam Subbey; Richard D.M. Nash; Anna S. Frank.

- A list of published articles incorporating some form of environmental driver was finalized, and WG members divided articles for compiling summary of each study's approach and conclusions. Submission planned for fall 2016.
- Presentation on model averaging (ensemble) for assessment models by JRC scientists; Ensemble averaging review of literature on methodologies, a presentation for a simple test case was given, identification of software (R packages, A4A/FLR framework).
- A more complex case study for ensemble forecasts was planned with JRC colleagues using the A4A/FLR software framework.
- 1 student thesis on topics of recruitment processes was completed between 2014 and 2016, with annual presentations made to WGRFE: Regulatory Factors on the Dynamics of a System of Delayed Differential Equations.
- A compilation of projection methodology was made for a broad representation of fisheries across 5 geographic management areas (North Sea, NW Atlantic, SW Atlantic, NE Pacific, and Pacific Islands).

5 Final report on ToRs, workplan and Science Implementation Plan

Progress and fulfilment by ToR

- ToR 1 – A summary of projection approaches was compiled for the regional management bodies (Annex 6); a review manuscript summarizing published studies that incorporated environmental drivers is drafted and submission is planned for fall 2016.
- ToR 2 – Three simulation studies were explored for this TOR: i) a simulation study that investigated the dynamics and emergent properties of a discrete-time, continuous-state, stage-structured (Egg-Larva-Juvenal-Adult) population dynamics model (this work constituted part of the thesis of WGRFE member Ute-Alexandra Schaarschmidt, and a manuscript has been submitted for publication); ii) a simulation study to investigate the properties (identifiability, precision and bias) of consecutive stock recruit functions (Paulik diagrams), as well as a fit to real data for North Sea Spring Spawning Herring (a manuscript is in draft form, submission planned for fall 2016); iii) a simulation study to determine whether recruitment autocorrelation could be estimated and whether it improved forecasts (this work was just published in Fisheries Research in June 2016).
- ToR 3 – Literature was reviewed on ensemble approaches, statistical frameworks for weighting models and evaluating performance, and a simple 2x2 case study for Georges Bank haddock on assessment model averaging combined with forecast averaging was evaluated at the 2016 meeting; a more complex presentation on assessment model averaging was presented by JRC scientists, and WGRFE is planning further collaboration with JRC scientists to extend their case study to include forecasting (to be pursued at WGRFE meeting in 2017).

Science highlights (key conclusions and products, publications emanating from projects identified at WGRFE meetings)

- Autocorrelation can be estimated from assessment estimates of recruitment (conditional on time series length and strong information content in data), and incorporating autocorrelation in forecasts tended to improve forecasts somewhat in the short term
- One student thesis explored WGRFE topic and was defended between 2014 and 2016
- The current summary of forecasting approach (Annex 6) indicates that no region is currently making forecasts that include environmental drivers; a common recruitment forecast is to use geometric mean recruitment or median recruitment for a specific period of time. A few regions project from the estimated stock-recruit function.
- Johnson, K.F., E. Councill, J.T. Thorson, E.N. Brooks, R.D. Methot, A.E. Punt. 2016. Can autocorrelation be estimated using integrated assessment models and how does it affect population forecasts? Fisheries Research 183:222-232.
- Paper submitted to Journal of Mathematical Biology on 'Emergent properties of a multi-stage population dynamic model', Ute A. Schaarschmidt; Sam Subbey; Richard D.M. Nash; Anna S. Frank
- Two manuscripts in preparation for submission: i) Unraveling the Recruitment Problem: A Review of Environmentally Informed Forecasting; ii) A State Space Implemention of Multi-stage Recruitment functions

6 Cooperation

WGRFE is currently cooperating with scientists at the EU-Joint Research Center, Marine Affairs Unit, in Ispra, ITALY for ToR c) to develop more complex case studies with supporting software for ensemble forecasting.

7 Summary of Working Group evaluation and conclusions

WG Evaluation

WGRFE has made contributions to the following research priorities (and sub priorities) of the Science Plan:

1) Ecosystem Processes and Dynamics (EPD) – Priority Area 4: Understand the influence of climate impacts across a range of temporal and spatial scales, from local to global and from seasonal to multidecadal and identify indicators of climate driven biotic responses and forecast trajectories of change;

2) Ecosystem Processes and Dynamics (EPD) – Priority Area 6: Investigate linear and non-linear ecological responses to change, the impacts of these changes on ecosystem structure and function, and their role in causing recruitment and stock variability, depletion, and recovery.

Future plans

1) A one-year extension of the WG beyond its current term is required because:
    - Time is needed to finalize manuscripts in preparation;
    - Testing and validation of methodologies (e.g., forecast ensemble modelling) is work in progress, and success is best guaranteed if this project continues under the auspices of the WG;
    - Collaboration with Joint Research Centre (Ispra, Italy) was initiated this year, and joint work will pursued before summer 2017, when another WGRFE is planned;
    - Application of some of the WG results to specific case studies is outstanding.
2) The WG will consider (after the extension) whether to apply for a renewal of the ToRs (and a new 3-year period).

A full Working Group evaluation is included in this report as Annex 4.

Annex 1: List of participants

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Working Group members at the Joint Research Centre in Ispra, Italy, June 2016.

Annex 2: Recommendations

WGRFE has no recommendations that arose from their meeting this year.

Annex 3: WGRFE terms of reference

A **Working Group on Recruitment Forecasting in a variable Environment** (WGRFE), chaired by Liz Brooks, USA, and Sam Subbey, Norway, will meet in Woods Hole, Massachussetts (USA), June 2017, to work on ToRs and generate deliverables as listed in the Table below.

WGRFE will report on the activities of 2017 by August 2017 to SSGEPD.

ToR descriptors

ToR	Description	Background	Science Plan topics addressed	Duration	Expected Deliverables
a	Report on conclusions and recommendations for future MSE studies that aim to incorporate environmental drivers to forecast recruitment	This review will highlight successes and failures of incorporating environmental drivers, and recommend best practice advice	1.4, 1.6	1 year	Review paper
b	Report on feasibility of identifying stage-specific environmental drivers in stock recruit functions	This will highlight limitations to complex modelling when >1 driver impacts different recruitment stages	1.4, 1.6	1 year	Peer review manuscript
c	Present results of ensemble forecasting	This will develop algorithms for blending forecasts from multiple models and build modules on existing software platforms, providing illustrations for implementation	1.4, 1.6	1 year	Software module within A4A/FLR; best practice advice

Summary of the Work Plan

Year 1	WORK ON ALL TOR

Supporting information

Priority	The current activities of this Group will lead ICES into issues related to how the environment and changes in climate may impact recruitment in the future, and best practice for capturing these effects when making forecasts from assessment models. Conclusions will be based on simulation studies, and case study examples with real data. Consequently, these activities are considered to have a very high priority.
Resource requirements	The research programmes which provide the main input to this group are already underway, and resources are already committed. The additional resource required to undertake additional activities in the framework of this group is negligible.
Participants	The Group is normally attended by some 13-15 members and guests.
Secretariat facilities	None.
Financial	No financial implications.
Linkages to ACOM and groups under ACOM	There are no obvious direct linkages.
Linkages to other committees or groups	There are no direct linkages at this time.
Linkages to other organizations	EC-Joint Research Centre, Marine Affairs Unit (Ispra, Italy)

Annex 4: Copy of Working Group evaluation

1) Working Group name: WGRFE

2) Year of appointment: 2014

3) Current Chairs: Liz Brooks (USA), Sam Subbey (Norway)

4) Venues, dates and number of participants per meeting:

Copenhagen, Denmark, 16–20 June 2014, 14 participants

Seattle, USA, 22–26 June 2015, 13 participants

JRC-Ispra, Italy, 13–17 June 2016, 13 participants

WG Evaluation

5) If applicable, please indicate the research priorities (and sub priorities) of the Science Plan to which the WG make a significant contribution. WGRFE is contributing to two Ecosystem Processes and Dynamics (EPD) Priorities:

- Priority 4: Understand the influence of climate impacts across a range of temporal and spatial scales, from local to global and from seasonal to multidecadal and identify indicators of climate driven biotic responses and forecast trajectories of change
- Priority 6: Investigate linear and non-linear ecological responses to change, the impacts of these changes on ecosystem structure and function and their role in causing recruitment and stock variability, depletion and recovery.

6) In bullet form, list the main outcomes and achievements of the WG since their last evaluation. Outcomes including publications, advisory products, modelling outputs, methodological developments, etc. This is the first self-evaluation for WGRFE, which has operated since 2014-2016.

- Johnson, K.F., E. Councill, J.T. Thorson, E.N. Brooks, R.D. Methot, A.E. Punt. 2016. Can autocorrelation be estimated using integrated assessment models and how does it affect population forecasts? Fisheries Research 183:222-232.
- Paper submitted to Journal of Mathematical Biology on 'Emergent properties of a multi-stage population dynamic model', Ute A. Schaarschmidt; Sam Subbey; Richard D.M. Nash; Anna S. Frank
- Two manuscripts in preparation for submission: i) Unraveling the Recruitment Problem: A Review of Environmentally Informed Forecasting; ii) A State Space Implemention of Multi-stage Recruitment functions
- Collaboration initiated with Joint Research Centre (Ispra, Italy) to develop ensemble forecasting in the A4A/FLR software framework

7) Has the WG contributed to Advisory needs? If so, please list when, to whom, and what was the essence of the advice.

- No direct advice has been provided yet.

8) Please list any specific outreach activities of the WG outside the ICES network (unless listed in question 6). For example, EC projects directly emanating from

the WG discussions, representation of the WG in meetings of outside organizations, contributions to other agencies' activities.

- N/A

9) Please indicate what difficulties, if any, have been encountered in achieving the workplan.

- NA

Future plans

10) Does the group think that a continuation of the WG beyond its current term is required? (If yes, please list the reasons) Yes, the WG believes a continuation is required:

- One project (ensemble forecasting) has just begun, and will be more fully developed in the coming year
- Two manuscripts are in preparation, to be submitted fall 2016, which will inform the remaining project
- A collaboration with Joint Research Centre (Ispra, Italy) has just been initiated. This work will also build on the ensemble forecasting project, specifically developing a generic software framework based on the A4A/FLR program
- We believe that useful advice will come from the two manuscripts in preparation about feasibility of incorporating environmental drivers into recruitment forecasting. Furthermore, the ensemble forecasting framework will provide a statistical approach to considering alternative hypotheses (or sensitivity to current assumptions). This can be useful in providing advice that incorporates uncertainty due to model choice and model assumptions, in addition to estimated assessment uncertainty.

11) If you are not requesting an extension, does the group consider that a new WG is required to further develop the science previously addressed by the existing WG.

- We are requesting an extension of 1 year, through 2017. We do not consider that a new WG is required.

(*If you answered YES to question 10 or 11, it is expected that a new Category 2 draft resolution will be submitted through the relevant SSG Chair or Secretariat*.)

12) What additional expertise would improve the ability of the new (or in case of renewal, existing) WG to fulfil its ToR?

- Current WG expertise is sufficient to accomplish the planned work.

13) Which conclusions/or knowledge acquired of the WG do you think should be used in the Advisory process, if not already used? (please be specific)

- We expect that advice about forecasting can be provided, in particular relating to whether explicit mechanistic drivers need to be included, or if simpler implicit approaches perform just as well. Examples of implicit approaches include autocorrelated recruitment (assuming that the driver is not random between years), allowing smooth changes in forecasted relationships (e.g., fitting a GAM), and developing flexible Harvest Control

Rules that respond to recent observations of biological parameters or recent recruitment levels.

Annex 5: Presentations and Associated Discussion

1.	Mellisa Haltuch	Unraveling the Rectuitment Problem: A Review of Environmental Informed Forecasting
2.	Jon Brodziak	Combining Forecasts Redux
3.	Jon Brodziak	Pretty Good Forecasting Practices
4.	Jon Brodziak	Background on Combining Forecasts
5.	Jon Brodziak	WGRFE Ensemble Forecasts of Recruitment Project: Pushing the Envelop
6.	Anna Frank	Predictability of Marine Population Trajectories under the Effect of Birth and Harvest Pulses
7.	Liz Brooks	Ensemble Forecasts: A Simple Illustration
8.	Finlay Scott	An Applied Framework for Incorporating Multiple Sources of Uncertainty in Fisheries Stock Assessment
9.	Richard Nash	Problems with time series–how long should they be? A case study of North Sea Autumn Spawning Herring (NSASH) with some consideration for Northeast Arctic Cod
10.	Iago Mosqueira	A quick demo of the FLR tools
11.	Kelli Jonhson	Can autocorrelated recruitment be estimated using integrated assessment models and how does it affect population forecasts?

Annex 5: Abstracts and Rapporteur Notes for WGRFE Meeting

Melissa Haltuch

Title: Unraveling the Recruitment Problem: Environmentally Informed Forecasting

Abstract

One of the WGRFE TORs were to "Review approaches (modelling and methodologies) where stock recruitment models incorporate external drivers, along with all caveats." A large number of journal publications from 2011 forward cite Basson (1999) and support the conclusion that including environmental indices in stock recruitment models results in no improvement with respect to fishery management performance. Specifically, Basson (1999) used Monte Carlo simulation to conclude that there is no gain in either conservation or average yield when an environmental factor is incorporated into short-term recruitment predictions for a gadoid-like life history. Furthermore, fishery management uncertainty can only be reduced when the environmental factor can be well predicted and if the interaction between the environmental factor and recruitment is strong. A final recommendation was that further simulation studies explore the implications and feasibility of incorporating environmental factors into Management Strategy Evaluations (MSEs), particularly across an array of life histories. This review paper aims to review progress in implementing environmental factors in MSE, and stock-recruitment projections, since the publication of Basson (1999) with the goals of 1) examining successes and challenges across studies that implement environmentally driven MSEs/ stock recruitment projections, and 2) highlighting study characteristics that lead to different results. This review concludes with an evaluation of what future studies need to do to be relevant to fisheries management, what are the critical questions that should be investigated through future MSE work.

Discussion Points

Workshop participants discussed the structure of the analyses for the draft manuscript and assignment of groups to work on each set of questions to be addressed. Participants agreed that draft analyses sections will be provided by 5 August 2016, after which Dr. Haltuch will produce a full draft manuscript for the group's review. The target journal is tentatively Fish and Fisheries.

Jon Brodziak

Title 1: Combining Forecasts Redux

Abstract

This presentation described the benefits of creating multiple forecasts of an event of interest and also the benefits of combining forecasts of recruitment to produce lower prediction errors. Using more than one forecast method can improve accuracy, noting that there is no true approximating model. Many things can affect the quality of forecasts and

this uncertainty can be captured by using alternative approaches that are credible. Combining forecasts can reduce errors due to faulty assumptions, biases, or mistakes in data. In general, it is appropriate to combined forecasts: when it is uncertain which forecasting method is most accurate; when the forecasting situation is new and few data are available; when it is important to avoid large errors because the costs of such errors are very high. In general, some recommended procedures to combine forecasts include using different methods or data to produce independent forecasts, using at least five forecasts, using formal procedures to combine forecasts, using equal forecast weights unless strong evidence exists to support unequal weighting of forecasts, using robust measures of central tendency, e.g. trimmed means, and using the forecast track record to vary the forecast weights if evidence is strong.

Title 2: Pretty Good Forecasting Practices

This presentation described a general purpose algorithm for incorporating assessment model uncertainty along with forecast model uncertainty to produce ensemble forecasts of recruitment and other quantities of interest for a fishery system. In general, the stock assessment process can be thought of as consisting of two steps. First, determine the best available assessment modelling information for management advice, noting that this could be based on a single best assessment model or an ensemble of models. Second, determine the best available forecast modelling information for management advice, noting that this could be based on a single best forecast model or an ensemble of models. Given the results of the assessment process, the management system can then evaluate the benefits and costs of alternative management actions using the best available assessment and forecast modelling information.

Title 3: Background on Combining Forecasts

This presentation covered the historical development of published research on combining forecasts. In particular, the information in the seminal article by Bates and Granger (1969) on the optimal combination of two independent forecasts was covered to provide background for more modern methods of ensemble forecasting. The generalization of Bates and Granger to combining more than two forecasts was also described along with the case of equal forecast weighting and the likely underpinnings of the forecast combination puzzle.

Title 4: WGRFE Ensemble Forecasts of Recruitment Project: Pushing the Envelope

This presentation covered the potential application of modern machine learning approaches to constructing forecast ensembles, such as random forests or boosted regression trees, to produce accurate forecasts of quantities of interest in dynamic fisheries systems. The value of ensembles was discussed along with the no free lunch principle which simply states that no single predictive algorithm wins all the time, or in all problems. When combing multiple independent and diverse algorithmic decisions, each of which is at least more accurate than random guessing, random errors tend to cancel each other out, and correct decisions are reinforced. Some algorithmic approaches to constructing an ensemble forecast that might be useful for recruitment included: Generalized cross validation (e.g., Efron 1981), Bayesian model averaging (e.g., Brodziak and Legault 2005), Bootstrap aggregating (i.e., bagging, Breiman 1996), Stacking (Wolpert 1992), Random forest (Ho 1995), AdaBoost (Freund and Shapire 1996), Boosted regression trees (e.g., review in Elith *et al.* 2008), ARCing (Breiman 1996), Gradient boosting (Friedman 1999), as well as subjective models, neural networks, and other variants. One overall goal of the WGRFE ensemble project was to produce analytics to perform ensemble forecasts of recruitment and other quantities of interest. Another goal was to produce a set of good examples, or at least a case study of ensemble forecasting as applied for recruitment forecasting from an existing stock assessment.

Anna Frank

Title: Predictability of Marine Population Trajectories under the Effect of Birth and Harvest Pulses

Abstract

This talk presents the analysis of a single-species and stage-structured model with focus on understanding (i) the effect of harvest and birth pulses, and (ii) the role of delays, in regulating the dynamics of the perturbed system and its predictability. Results from numerical experiments will be presented.

Liz Brooks and Jon Brodziak

Title: Ensemble Forecasts: a simple illustration

Abstract

A simple 2X2 case study was presented to highlight an approach to ensemble forecasts that begins with defining and averaging multiple assessment models, assigning weights based on mean squared error of each assessment model, and then performing 3-year forecasts with two alternative forecast models. A subset of the full available time series was fit in the first iteration of assessment, then a 3-year forecast was made. In the second iteration, the two assessment models were applied through the first forecast interval so that forecast performance could be evaluated and then forecast model weights updated. The illustration compared results of applying different weighting schemes to 3 quantities of interest in a forecast: recruitment, spawning biomass, and catch. The case study chosen concluded that in 3-year forecasts, different recruitment models did not have much influence on forecast accuracy of spawning biomass or catch, because the stock (haddock, *Melanogrammus aeglefinus*), are not mature until 3-4 years and have low fishery selectivity at the youngest ages.

Finlay Scott

Title: An Applied Framework for Incorporating Multiple Sources of Uncertainty in Fisheries Stock Assessments

Abstract

Estimating fish stock status is very challenging given the many sources and high levels of uncertainty surrounding the biological processes (e.g. natural variability in the demographic rates), model selection (e.g. choosing growth or stock assessment models) and parameter estimation. Incorporating multiple sources of uncertainty in a stock assessment allows advice to better account for the risks associated with proposed management options, promoting decisions that are more robust to such uncertainty. However, a typical assessment only reports the model fit and variance of estimated parameters, thereby underreporting the overall uncertainty. Additionally, although multiple candidate models may be considered, only one is selected as the 'best' result, effectively rejecting the plausible assumptions behind the other models. We present an applied framework to integrate multiple sources of uncertainty in the stock assessment process. The first step is the generation and conditioning of a suite of stock assessment models that contain different assumptions about the stock and the fishery. The second step is the estimation of parameters, including fitting of the stock assessment models. The final step integrates across all of the results to reconcile the multi-model outcome. The framework is flexible enough to be tailored to particular stocks and fisheries and can draw on information from multiple sources to implement a broad variety of assumptions, making it applicable to stocks with varying levels of data availability The Iberian hake stock in International Council for the Exploration of the Sea (ICES) Divisions VIIIc and IXa is used to demonstrate the framework, starting from length-based stock and indices data. Process and model uncertainty are considered through the growth, natural mortality, fishing mortality, survey catchability and stock-recruitment relationship. Estimation uncertainty is included as part of the fitting process. Simple model averaging is used to integrate across the results and produce a single assessment that considers the multiple sources of uncertainty.

Richard Nash

Title: Problems with time series – how long should they be? A case study of North Sea Autumn Spawning Herring (NSASH) with some consideration for Northeast Arctic Cod

Abstract

The stock and recruitment pairs available for North Sea Autumn Spawning Herring (*Clupea harengus*) are from 1947 to the present (2015). Within this time period the stock declined from a high level in the late 1940s to a stock collapse and fishery closure in the mid to late 1970s. After the closure the stock rebuilt to a high at the end of the 1980s and then again to the early 2000s. The slowdown in stock increase, both in the late 1980s and early 2000s was accompanied by lower than expected recruitment for the size of the stock. In fact the most recent phase (2002 to the present) has shown abnormally low and sustained

low levels of survival from hatched larvae to late larvae. This indicates a low level of productivity within the North Sea herring stock which has been persistent since 2002. Often the Stock and Recruitment relationships are used to give a perception of the stock, its general dynamics and in fishery related reference points. Clearly the dynamics in the most recent period are different from the period prior to 2000, however, there is a possibility that the present survival rates of the early life history stages may be similar to the late 1940s and early 1950s. Also the ecosystem has changed to a certain extent with different physical conditions (some due to e.g. global warming, AMO effects etc.) and biological interactions (predator-prey and competition interactions). Therefore, how many years should we utilize to understand the dynamics of a stock? We will look at the perception of the herring stock dynamics using a range of years and the problems of using severely truncated time-series. In addition, the time series for northeast Arctic cod is also brought up for discussion. We will also ask the question, 'how should we deal with problem'? This presentation is not intended to provide answers but to initiate a discussion that may provide a way forward.

Iago Mosqueira

Title: A quick demo of the FLR tools

Abstract

A short demonstration of the current capabilities of the FLR (Fisheries Library in R) toolset including those related to stock-recruitment fitting, model selection and forecasting. The R packages in the FLR toolset includes a range of stock assessment models, which can be easily run on the same datasets, their results compared, and then combined using other tools in the R language, like ensembles and regression trees. The forecasting methods in FLR can also accommodate multiple scenarios on future recruitment dynamics. Future versions, currently under development, will allow for more detailed modelling of the biological processes involved in recruitment, and forecasting on complex fisheries with multiple fleets and stocks.

Kelli Johnson

Title: Can autocorrelated recruitment be estimated using integrated assessment models and how does it affect population forecasts?

Abstract

The addition of juveniles to marine populations (termed "recruitment") is highly variable due to variability in the survival of fish through larval and juvenile stages. Recruitment estimates are often large or small for several years in a row (termed "autocorrelated" recruitment). Autocorrelated recruitment can be due to numerous factors, but typically is attributed to multi-year environmental drivers affecting early life survival rates. Estimating the magnitude of recruitment autocorrelation within a stock assessment model and examinations on its effect on the quality of forecasts of spawning biomass within stock

assessments is uncommon. We used a simulation experiment to evaluate the estimability of autocorrelation within a stock assessment model over a range of levels of autocorrelation in recruitment deviations. The precision and accuracy of estimated autocorrelation, and the ability of an integrated age-structured stock assessment framework to forecast the true dynamics of the system, were compared for scenarios where the autocorrelation parameter within the assessment was fixed at zero, fixed at its true value, internally estimated within the integrated model, or input as a fixed value determined using an external estimation procedure that computed the sample autocorrelation of estimated recruitment deviations. Internal estimates of autocorrelation were biased toward extreme values (i.e., towards 1.0 when true autocorrelation was positive and -1.0 when true autocorrelation was negative). Estimates of autocorrelation obtained from the external estimation procedure were nearly unbiased. Forecast performance was poor (i.e., true biomass outside the predictive interval for the forecasted biomass) when autocorrelation was ignored, but was non-zero in the simulation. Applying the external estimation procedure generally improved forecast performance by decreasing forecast error and improving forecast interval coverage. However, estimates of autocorrelation were shown to degrade when fewer than 40 years of recruitment estimates were available.

Discussion Points

It was noted in discussion that it would be beneficial to investigate the relationship between autocorrelation and forecasts with other stock-recruitment functions, notably the miss-specification between the operating and estimation method using Beverton-Holt and Ricker stock-recruit functions and the simpler specification of deviations about a mean. Additional discussions were generated around the bias in forecasts when autocorrelation is zero and the estimation method was fixed at zero, how bias adjustment fits into the model predictions, and what would happen for other life histories such as tuna or sardine.

Annex 6: Table summarizing Projection Approaches

Mgmt Body/ region	**Life history or stock**	**Proj length**	**Proj assmpt**	**Recr model**	**Envir driver used?**	**Control Spec**	**Quant meas**	**Software**
Northeast US (NEFMC)	groundfish	3-5 years	3-5 yr ave for selectivity; maturity; weights	- empirical cdf; sometimes multi-stage empirical cdf	no	F or catch	Catch, ssb	AGEPRO (NMFS Toolbox program)
Northwest US (PFMC)	groundfish	10 years	Recent selectivity, growth, fleet allocations	Internally specified recruitment model with sigma recruitment; fraction of the log-bias adjustment	no	F or catch	Ssb, stock status (depletion), catch, recruitment, reference points	SS3
Southeast US – (SAFMC)	Reef fish	5-50 yr	3-yr avg for selectivity and fleet allocation	Typically, Beverton-Holt model with lognormal deviations.	no	F or catch, usually F	SSB, landings, discards, probability of overfishing, probability of overfished (depletion)	Projection model coded in R, customized to stock and management scenarios.
ICES North	saithe	3	3yr ave for	Resampled medi-	NO	F or catch, ssb	Catch, ssb, F	SAM

Sea			selectivity; maturity; weights	an from 2002 to present		target in year 3		
ICES- North Sea	Saithe 3a46	3*	ICES standard protocol*	Resampled median from 2002 to present	NO	F or catch, SSB target in year 3	Catch, SSB, F	SAM
ICES- North Sea	Cod 3a47d	3*	ICES standard protocol*	Resampled median from 1998 to present	NO	F or catch, SSB target in year 3	Catch, SSB, F	SAM
ICES- North Sea	Haddock 3a46	3*	ICES standard protocol*	Assessment model forecast	NO	F or catch, SSB target in year 3	Catch, SSB, F	FLR
ICES- North Sea	Plaice 7d	3*	ICES standard protocol*	Geometric mean 2010-2013	NO	F or catch, SSB target in year 3	Catch, SSB, F	FLR
ICES- North Sea	Plaice 3a4	3*	ICES standard protocol*	Geometric mean 1957–2013	NO	F or catch, SSB target in year 3	Catch, SSB, F	FLR
ICES- North Sea	Sole 7d	3*	ICES standard protocol*	Geometric mean (excluding 2013-2015)	NO	F or catch, SSB target in year 3	Catch, SSB, F	FLR

ICES- North Sea	Sole 4	3*	ICES standard protocol*	RCT3 + GM (year 2) 1957-2012	NO	F or catch, SSB target in year 3	Catch, SSB, F	FLR
ICES- North Sea	Sprat 4	3*	ICES standard protocol*	Geometric mean (1996–2015)	NO	F	Catch, SSB	SMS
ICES- North Sea	Whiting 47d	3*	ICES standard protocol*	RCT3 & GM (year 2,3) 1990-2015	NO	F or catch, SSB target in year 3	Catch, SSB, F	FLR
ICES- North Sea	Nephrops				NO		Catch, F	
ICES- North Sea	Herring 47d	3*	ICES standard protocol*	Year 1 Assess output, Geometric mean 2002-present for second 2 years	No	F or catch, SSB target in year 3	Catch, SSB, F	SAM