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

12–16 June 2017

Woods Hole, USA

ICES International Council for the Exploration of the Sea

CIEM 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.

A second meeting of the WGRFE was held 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.

With a request for an additional year granted, WGRFE held a fourth meeting at the Woods Hole Oceanographic Institute in Woods Hole, USA, 12–16 June 2017. Four public presentations were made, and attended by scientists in the Woods Hole community (WHOI and NOAA). The presentations included updates on the simulation study of multi-stage recruitment functions, a case study examining whether causal drivers can be identified for Barents Sea Capelin, and an overview of ocean process studies in the California Current. There was also a presentation on the "assessments for all" (a4a) computing framework, and a hands on session to demonstrate some of the capabilities. There was strong interest among WG members to continue a collaboration on the topic of ensemble modelling, and future work within the a4a environment will be pursued in another forum. The WG drafted a proposal for a symposium theme session for the 2018 ICES Annual Science Conference on Model Ensembles, and hopes to contribute talks

based on products from this WG and the continued collaboration between the members. There were several working sessions during the meeting that were devoted to manuscript drafting. Substantial progress was made on the review paper on successes and challenges of incorporating environmental drivers in forecasts, as well as progress drafting the manuscript for the multi-stage recruitment functions. Several discussion sessions focused on the methodology of combining forecasts, with a focus on alternatives for weighting individual models in the ensemble.

1 Administrative details

Working Group name

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

Year of Appointment within current cycle

2014

Reporting year concluding the current three-year cycle (with 1-year extension)

4

Chair(s)

Samuel Subbey, Norway

Elizabeth Brooks, USA

Meeting venues and dates

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

22-26 June 2015, Seattle, USA (13 participants)

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

12-16 June 2017, Woods Hole, MA, USA (10 participants)

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
Years 3&4	Testing, validation and documentation of models and methodologies for peer review, manuscript drafting

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 multistage 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 sections 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 (in revision, as at October 2017).

- 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 late 2017.
- 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 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).

Summary—Year 4 (requested year of extension)

- Complete draft of manuscript reviewing incorporation of environmental drivers; presentations at AFS and CAPAM;
- Completion of Paulik simulations and progress on manuscript with presentations at CAPAM;
- Autocorrelation work to be presented at 2017 ICES ASC and CAPAM;
- WG submitted proposal for theme session on Ensemble Models for 2018 ICES ASC;
- This WG will close and develop plans for future collaboration in another forum;
- Four public presentations made during WG meeting in Woods Hole, MA USA.

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 late 2017.
- 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 PhD 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 late fall 2017); iii) a simulation study to determine whether recruitment autocorrelation could be estimated and whether it improved forecasts (this work was 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 (this was pursued at WGRFE meeting in 2017).

Science highlights (key conclusions and products, publications emanating from presentations made and 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); 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.
- Brooks, E.N. and C.M. Legault. 2016. Retrospective forecasting – evaluating performance of stock projections for New England groundfish stocks. Can. J. Fish. Aquat. Sci. 73: 935-950.
- 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 (in revision).
- Two manuscripts in preparation for submission late fall 2017: i) Unravelling the Recruitment Problem: A Review of Environmentally Informed Forecasting; ii) A State Space Implementation 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 3-year term was granted for the following reasons:

- 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 meeting is scheduled;
- Application of some of the WG results to specific case studies is outstanding.

2) Satisfactory progress was made in this fourth year to address the outstanding work on ToR. The WG decided not to ask for a new 3 year term.

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

Annex 1: List of participants

Woods Hole, MA, USA, 2017 meeting

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Working Group members at the Woods Hole Oceanographic Institute, Woods Hole, MA, USA, June 2017.

Annex 2: Recommendations

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

Annex 3: WGRFE terms of reference

The **Working Group on Recruitment Forecasting in a Variable Environment** (WGRFE), chaired by Samuel Subbey, Norway, and Elizabeth Brooks, USA, and work on ToRs and generate deliverables as listed in the Table below.

	Meeting dates	Venue	Reporting details	Comments (change in Chair, etc.)
Year 2014	16–20 June	ICES, Copehnagen, Denmark	Interim report by 1 August 2014 to SSGEPD	
Year 2015	22–26 June	Seattle, Washington (USA)	Interim report by 1 August 2015 to SSGEPD	
Year 2016	13–17 June	Ispra, Italy	Final report by 1 August to SCICOM	
Year 2017	12–16 June	Woods Hole, USA	Report by 1 August to SCICOM	Extension by 1 year

ToR descriptors

ToR	Description	Background	Science Plan topics addressed	Duration	Expected Deliverables
a	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).	a) Science Requirements	141, 335, 336	Year 1	Review paper
b	Develop prototype, statistical recruitment tools for selected stocks, based on stage-structured models which include environmental drivers and multispecies considerations	a) Science Requirements b) Advisory Requirements	141, 335, 336	Year 2	Prototype models developed on a common platform (e.g. AD Model Builder)
c	Testing, validation and documentation of prototype models.	a) Science Requirements b) Advisory	141, 335, 336	Year 3	Tested and validated computer codes

		Requirements			in R (ADMB) for stock recruitment forecasting. Documentation of methodologies and models
a (year 4)	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	Year 4	Review paper
b (year 4)	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	Year 4	Peer review manuscript
c (year 4)	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	Year 4	Software module within A4A/FLR; best practice advice

Summary of the 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
Year 4	Work on ToRs d, f, g

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: WGRFE self-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
- Presentation at the American Fisheries Society (Tampa, FL USA) and at the Center for the Advancement of Population Assessment Methodology (Miami, FL USA) "Unraveling the Recruitment Problem: A Review of Environmentally Informed Forecasting" (Tampa, FL USA)

- Presentation at the Center for the Advancement of Population Assessment Methodology "Paulik revisited: Statistical framework and estimation performance of multistage recruitment functions" (Miami, FL USA)

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)

- No.

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.

- No.

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.
- The state space framework for multi-stage recruitment processes could have some implications for approaches that fit stock recruit functions to assessment output while ignoring both observation and process error. Specifically, we are examining the ability to identify the correct functional form and associated parameters, and whether priors can be identified in reality for both measurement and process error.

Annex 5: Public Presentations and Abstracts

1. Ernesto Jardim: Making MSE algorithms 'user friendly' – the a4a standard MSE

2. Liz Brooks: Paulik revisited: Statistical framework and estimation performance of multistage recruitment functions

3. Sam Subbey: Causal Drivers of Barents Sea Capelin Population Dynamics on Different Time Scales

4. Brian Wells: Process studies to quantify ecosystem dynamics in the California Current

Making MSE algorithms 'user friendly' – the a4a standard MSE

Ernesto Jardim, Finlay Scott, Iago Mosqueira

European Commission Joint Research Centre, Ispra, Italy

Abstract

Management Strategy Evaluation (MSE) algorithms are complex simulation frameworks which require long periods to setup and code. The algorithm mechanics and analysis of results is complicated which makes communication with collaborators and stakeholders challenging. The Assessment for All (a4a) initiative of the Joint Research Centre (JRC) is developing a standard MSE algorithm, which tries to make these processes more efficient and create a common lexicon which, hopefully, will allow a wider audience to get involved in MSE development and discussion. This talk will address the formalization of the a4a MSE and the code implementation concepts, with a demonstration of the program and the opportunity for interactive questions. The a4a MSE was used to advise the European Commission on the implementation of multi-annual management plans for the Northwest Mediterranean demersal stocks in 2015 and 2016. If there is interest, we may arrange a lunch time hands-on session (you will need R 3.3.x and R studio).

Paulik revisited: Statistical framework and estimation performance of multistage recruitment functions

Liz Brooks

Northeast Fisheries Science Center, NOAA, Woods Hole, MA

Abstract

A wide variety of processes act at different stages and different intensities within the timeline between spawning and the age designated as "recruitment." It is common practice to collapse this complex series of sequential stages into a single process between spawning stock size and resultant recruitment. Reasons for treating this as a single stage include lack of data on the intermediate stages, lack of understanding of the mechanisms and functional form governing intermediate stages, as well as lack of computational re-

sources to model a multi-stage process in the appropriate statistical framework. Using a simulation study, we explore the estimation of multi-stage stock recruit functions in a state space framework. Factors explored include the number of stages, the form of density dependence, the magnitude of measurement error associated with each stage, and the magnitude of process error between stages. We summarize results in terms of parameter identifiability, bias, precision, and ability of the model selection criteria to identify the correct underlying model. We also fit a single composite stock recruit function to the first and last simulated stage, the status quo practice, and compare the resulting inference about shape of the stock recruit function (asymptotic or overcompensatory) and characterization of uncertainty. We conclude with a discussion of general recommendations and management implications.

Causal Drivers of Barents Sea Capelin Population Dynamics on Different Time Scales

Sam Subbey

Institute of Marine Research, Bergen, Norway

Abstract

The dynamics of marine populations are usually forced by biotic and abiotic factors occurring at different intensity levels and time scales. Deriving the time frame within which each factor has a causal influence is important for predicting population trajectories. I shall present a statistical methodology for establishing (i) the strength of causal coupling between population dynamics and environmental (biotic and abiotic) factors, and (ii) the time scales over which causal covariates have significant influence on the population dynamics. The methodology is based on combining a multivariate autoregressive (MAR) model fit to data (to determine causal direction) with a quantification of the Relative Power Contribution (RPC) of covariates in frequency domain (to quantify the strength of connection). The methodology is applied to test the existence of causal coupling between the capelin biomass and a selected number of covariates identified in the literature.

Process studies to quantify ecosystem dynamics in the California Current

Brian Wells

Southwest Fisheries Science Center, NOAA, Santa Cruz, California

Abstract

I review a suite of biophysical factors in the Northeast Pacific Ocean Basin and California Current shelf ecosystem that directly or indirectly relate to forage, Chinook salmon (*Oncorhynchus tshawytscha*), and seabird productivity in central California. The synthesis of our work over the last decade provides a framework for integrating ecosystem process studies with empirical hypothesis testing to benefit fisheries management. Our hypothesis includes seasonality (phenology) as a key element determining forage, Chinook salmon, and seabird productivities. The strength and location of the North Pacific High Pressure System in winter influences shelf ecosystem productivity *via* "bottom-up" mechanisms and retention of key prey (euphausiid crustaceans and juvenile rockfishes, *Sebastes* spp.) in nearshore habitats prior to and during salmon out-migration to sea and

seabird chick rearing. Prey retention regionally is associated with increased consumption of krill and juvenile rockfishes by salmon and seabirds and is positively correlated with juvenile salmon ocean survival and fledgling success of seabirds. As a case study, the effects of ecosystem-level interactions were related to salmon survival. We found, during warmer, fresher, and stratified conditions (i.e., subtropical, less productive) common murres (*Uria aalge*) occur in larger aggregations and forage more inshore, where they forage predominantly on adult northern anchovy (*Engraulis mordax*). While foraging inshore, common murre consumption of juvenile Chinook salmon increases from 0 to 9% of their diet, which relates negatively to the salmon survival rate. Ultimately, we demonstrate through empirical study of ecosystem interactions the significance of top-down impacts on salmon associated with bottom-up dynamics. This information can be used to parameterize ecosystem models and develop benchmarks and trophodynamic thresholds to evaluate likely outcomes of ecosystem management options, including considerations of three fishery resources and recovering seabird populations.

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