ICES WGS2D REPORT 2018

ECOSYSTEM PROCESSES AND DYNAMICS STEERING GROUP

ICES CM 2018/EPDSG:22

REF. SCICOM

Interim Report of the Working Group on Seasonal to Decadal Prediction of Marine Ecosystems (WGS2D)

27–31 August 2018

ICES Headquarters, Copenhagen, Denmark

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

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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

Recommended format for purposes of citation:

ICES. 2018. Interim Report of the Working Group on Seasonal to Decadal Prediction of Marine Ecosystems (WGS2D), 27–31 August 2018, ICES Headquarters, Copenhagen, Denmark. ICES CM 2018/EPDSG:22. 42 pp.
https://doi.org/10.17895/ices.pub.8096

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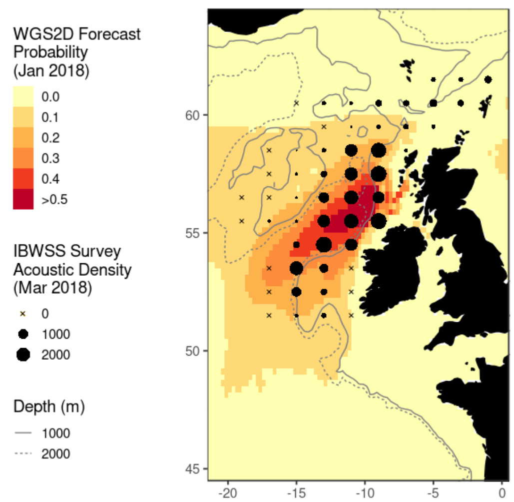
Executive summary

The ICES Working Group on Seasonal to Decadal Prediction of Marine Ecosystems (WGS2D), chaired by Mark R. Payne, Denmark, met for the second time in Copenhagen, Denmark, 27–31 August 2018. The group aims to develop and operationalise forecasts of marine ecological properties (e.g. distribution, recruitment, phenology) that are of direct relevance to ICES advice and monitoring activities.

WGS2D's first forecast product, for the spawning habitat of Blue whiting, has now been through one full cycle of making a forecast and then verifying the result. Good agreement was found between the forecast habitat and the observed distribution (see Figure), particularly in the core region, confirming a successful forecast. Refinements to the forecasting system have been made based on the lessons learn from this first iteration.



Comparison of forecast habitat and observed distribution for the 2018 blue whiting spawning season.

The Blue whiting spawning habitat forecast was updated for the 2019 spawning season. The forecast suggest a continuation the highly compacted distribution seen in recent years.

A new forecast product, for the feeding habitat of Bluefin tuna was produced and is now being delivered operationally. The forecast for the 2019 feeding season suggests the total area of thermally suitable habitat will be lower than the peaks seen in 2010 and 2012, although the amount of habitat is expected to remain above that seen prior to the mid-1990s.

Several new case studies have also been initiated and are currently under development. These include the spatial distribution of Saithe, and recruitment prediction for Sandeel, Barents Sea Cod, and Iberian Sardine. Requests for climate projection data for use in integrated assessments were answered. A request to examine the predictability of mackerel spawning distribution was also examined, but there does not appear to be sufficient scientific support for developing a forecast product.

During 2018, WGS2D also co-sponsored a theme session titled "From prediction to projection: the role of seasonal to decadal forecasts in a changing climate" at the Fourth International Symposium on the Effects of Climate Change on the World's Oceans (ECCWO) in Washington DC, USA, 4–8 June 2018. The session was co-sponsored in collaboration with WGS2D's sister working group within PICES, WG-CEP. The session was well subscribed and well attended, and has helped to raise the profile of ecological forecasting within the ICES and PICES communities.

1 Administrative details

Working Group name

Working Group on Seasonal to Decadal Prediction of Marine Ecosystems (WGS2D)

Year of Appointment within current cycle

2017

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

2

Chair(s)

Mark R. Payne, Denmark

Meeting dates

27–31 August 2018

Meeting venue

ICES HQ, Copenhagen, Denmark

2 Terms of Reference

a) Identify case studies
Predictable biological variables that are potentially useful to end-users will be identified by: i) Surveying the current needs within the ICES community for ecological forecast products for direct use in planning and advice; and ii) Reviewing the state of knowledge about links between the physical environment and biological response variable

b) Review methods for assessing predictability
Methods to evaluate the confidence level associated with ecological forecast products using both qualitative and quantitative metrics will be reviewed and where necessary, developed

c) Assess predictability of selected case studies
The predictability of the selected case studies identified in ToR a) will be assessed using the tzools identified in ToR b)

d) Develop protocols for operational delivery of ecological forecast products
Protocols for the operational delivery of ecological forecast products to end-users in the wider ICES community will include open-source code for processing data and generating predictions, and standardized formats for communicating the scientific basis, skill and uncertainties associated

e) Delivery of forecast products
Case studies that demonstrate an acceptable degree of predictive skill in ToR c) will be converted to operational products following ToR d
f) Joint activities with PICES SG-CEP
Outline a future research programme and coordinate joint workshop with the PICES Study Group on Climate and Ecosystem Predictability (SG-CEP)

3 Summary of Work plan

- Year 1: Identify case studies. Review methods for assessing predictability. Develop protocols for delivering products operationally.
- Year 2: Assess the predictability of identified case studies.
- Year 3: Joint activities with PICES SG-CEP. Development and delivery of operational forecasts.

4 List of Outcomes and Achievements of the WG in this delivery period

- Consolidation of the group, with a substantial increase in membership, to the point where the group is now viable. Nevertheless, new members and case studies will be needed in the future to maintain the group.
- **ECCWO theme session.** The WGS2D co-sponsored theme session titled "From prediction to projection: the role of seasonal to decadal forecasts in a changing climate" was held at the Fourth International Symposium on the Effects of Climate Change on the World's Oceans (ECCWO) in Washington DC, USA, 4–8 June 2018. The session was co-sponsored in collaboration with WGS2D's sister working group within PICES, WG-CEP. The session was well subscribed and well attended, and has helped to raise the profile of ecological forecasting within the international marine community.
- **Forecast verification**. The agreement between the first forecast produced by WGS2D last year (for Blue whiting spawning habitat) and the observations from the acoustic survey on this stock, was checked. Good agreement was found, particularly in the core area of the distribution. This first forecasting exercise was therefore viewed as successful.
- **Forecast updated**. The Blue whiting spawning habitat forecast was updated for the 2019 spawning season. The forecast suggest a continuation the highly compacted distribution seen in recent years.
- **New forecast product**. A new forecast product, for the feeding habitat of Bluefin tuna was produced and is now being delivered operationally. The forecast for the 2019 feeding season suggests the total area of thermally suitable habitat in this region will be lower than the peaks seen in 2010 and 2012, although the amount of habitat is expected to remain above that seen prior to the mid-1990s.
- **New case studies**. New members of the group brought with them several new case studies, which are now currently under development. These include the

spatial distribution of Saithe, and recruitment prediction for Sandeel, Barents Sea Cod, and Iberian Sardine.

- **ICES Prediction Cup 2019**. WGS2D is exploring the idea of "crowdsourcing" forecasts from within the ICES community and has had a networking activity accepted for the ICES ASC in 2019. Members of the ICES community will compete to produce the best forecast and be crowned the ICES forecasting champion for 2019.

5 Progress report on ToRs and workplan

ToR a) Identify case studies

During the past year, WGS2D has worked to both raise awareness of the group and the concept of marine ecological forecasting, with a view to collecting more case studies that could form the basis of ecological forecast products. In particular, the group has had contact and presented itself to the following ICES groups:

- WKPELA 2018 – Benchmark Workshop on Pelagic Stocks
- HAWG – Herring Assessment Working Group for the Area South of 62° N
- WGIPS – Working Group of International Pelagic Surveys
- WKMLEARN – Workshop on Uses of Machine Learning in Marine Science
- WGIPEM – Working Group on Integrative, Physical-biological and Ecosystem Modelling
- WGINOSE – Working Group on Integrated Assessments of the North Sea
- WGEAWESS – Working Group on Ecosystem Assessment of Western European Shelf Seas
- WKREDFISH – Benchmark Workshop on Redfish in Northeast Arctic waters
- WGCHAIRS – Annual Meeting of ICES Expert Group Chairs

These contacts have identified the following new potential case studies, where seasonal-to-decadal forecast information could be used, as follows:

- WKPELA / HAWG – Forecasting of North Sea autumn spawning herring recruitment

Furthermore, new members of the working group this year have also brought with them new ideas and potential case studies, where there is both a need for a forecast product, and scientific knowledge that could potentially support it:

- Anne Britt Sandø – Forecasting of Barents Sea cod recruitment, based on the recently published work of Årthun *et al.* (2018)
- Jennifer Devine – Forecasting of Saithe distribution and dynamics in the North Sea, for use in monitoring applications
- Susana Garrido – Forecasting of Sardine recruitment around the Iberian peninsula, based on published work of Garrido *et al.* (2017).
- Ole Henriksen / Martin Lindegren – Forecasting of sandeel recruitment in the North Sea, based on published work by Lindegren *et al.* (2018).

The group received two recommendations / requests from other working groups for forecast products

- WGMEGS - Working Group on Mackerel and Horse Mackerel Egg Surveys – request for distributional forecasts of Mackerel, for use in planning and performing the triannual egg survey on this stock.
- WGINOSE and WGEAWESS – Request for forecast information to incorporate into integrated assessments

These new case studies then complement existing case studies already identified at the first meeting of WGS2D:

- Blue whiting spawning habitat forecast, for use by WGIPS in planning monitoring activities on this stock
- Bluefin tuna feeding distribution
- Baltic sprat recruitment

Together this forms a total of ten potential case studies that are being examined by WGS2D. Work will continue on this ToR to gather other potential case studies in the future, but will be given a lower priority, as the main focus will move toward evaluating these case studies.

ToR b) Review methods for assessing predictability

No work was performed on this ToR at this years meeting, as the primary person behind it, Anna Miesner, was on parental leave. Work at the first meeting and during the ensuing year has reviewed methods for assessing the predictive skill of ecological forecasts. This work draws on the large pool of knowledge existing within meterology about how to validate and communicate the predictive skill of a forecast and the lessons from that discipline are already being incorporated into the forecast sheets produced by the group. A review paper on the topic is in preparation and is planned to be submitted before the next WGS2D meeting.

ToR c) Assess predictability of selected case studies

Skill assessment has been performed for the two case studies that are currently operationalised into forecast products (blue whiting, Bluefin tuna), and included on the forecast sheets: see Annex 4 and Annex 5 for details.

A forecast verification was made for the forecast of the blue whiting spawning habitat issued by WGS2D in autumn 2018, by comparing the observed and forecast distributions (Figure 1). This comparison showed generally good agreement, particularly in the east-west direction, which is as the main axis of variability in this stock. Agreement in the north-south direction was poorer, and may reflect the detection of pre- or post-spawning fish on their way to/from the spawning grounds. This exercise also revealed a weakness with the presentation of the forecast: the forecast is previously presented as a snapshot on a given date in the middle of the spawning season. However, this has the side effect of missing spawning activity in the souther and northern extremes of the distribution, which are respectively earlier and later. The revised forecast for the 2019 spawning season incorporates these refinements.

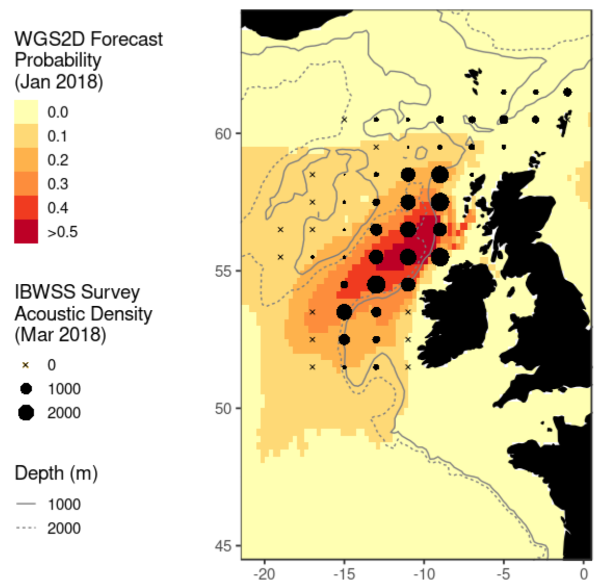


Figure 1. 2018 blue whiting spawning habitat forecast verification. Comparison of forecast habitat and observed distribution for the 2018 spawning season. The forecast spawning habitat is reproduced from the January 2018 WGS2D forecast (Forecast sheet 001-v02.1) and is represented as coloured areas, corresponding to the probability of observing blue whiting larvae in a single haul performed by the Continuous Plankton Recorder. Acoustic density (sA values) observed in 2018 IBWSS survey are plotted as circles whose area is proportional to the sA value – crosses indicate no-values. The 1000m and 2000m isobaths are added for reference.

Work has also been performed on assessing the predictability of the following case studies

- Mackerel egg survey. See Annex 2 for a summary of this work, and conclusions drawn
- WGINOSE / WGEAWESS. See Annex 2.
- Saithe distribution. Work has commenced on forecasting of this distribution. However, this remains at an early stage of exploration.
- Forecasting of Sandeel, Baltic sprat, Barents Sea cod and Sardine recruitment. Each of these case studies has a number of scientific papers behind it to support the link between the physical environment and the biological response: however, this work tends to be explanatory / descriptive in nature, and the predictive skill of the predictors have not been adequately addressed. Work has therefore begun on the assessing these relationships from a predictive angle.

ToR d) Develop protocols for operational delivery of ecological forecast products

Following on from the first WGS2D, the group is continuing to produce its forecasts using the WGS2D "forecast sheet" template developed previously. These sheets are intended to be conceptually similar to an ICES Advice Sheet and follow a similar structure and style to communicate the essential elements of the forecast to end-users. Further refinements and tweaks to this format have been made to improve the usefulness to users.

Work has also been performed on standardising the code to generate these forecasts and bringing it up to a standard suitable for publication in an open repository. A repository for WGS2D within the ICES GitHub repository (https://github.com/ices-eg/wg_WGS2D) hosts the necessary code and allow for ready updating of forecast sheets. Code for the first two forecast sheets (Blue whiting and Bluefin Tuna) is now available in this repository.

ToR e) Delivery of forecast products

WGS2D now has two forecast products that are being delivered in an operational manner. These are:

- Blue whiting spawning habitat forecast, for use by WGIPS in planning monitoring activities on this stock. This forecast was developed at the 2017 meeting and the forecast of the March 2018 spawning distribution was delivered to WGIPS at their January 2018 meeting. A comparison of the forecast and subsequently observed distributions has been made , and showed good agreement (Figure 1). The forecast has been updated for the 2019 spawning season. The spawning distribution for March 2019 is expected to be highly compressed against the continental shelf edge, reflecting the continuing current unusual oceanographic conditions in the region. Minimal spawning on or to the west of Rockall Plateau is expected. In historical terms, the westward extent of spawning is forecast to be among the lowest since 1950, and the spawning area also low. Full details of this forecast product are included in Annex 4. The forecast will be updated as the spawning season and survey approaches, and will be available online at http://www.fishforecasts.dtu.dk/forecasts/blue-whiting-spawning-habitat
- Bluefin tuna feeding habitat forecast. This forecast is based on work presented at WGS2D this year, and serves to illustrate how a forecast product can be coupled to operational seasonal- and decadal-forecast systems. While there is no direct user for this forecast system as yet, WGS2D is working to identify potential users of the forecast that can help refine it. The forecast for 2019 suggests that the total area of thermally suitable habitat in this region will be lower than the peaks seen in 2010 and 2012, although the amount of habitat is expected to remain above that seen prior to the mid-1990s. Full details of this forecast product are included in Annex 5. The forecast will be updated as the feeding season approaches, and will be available online at http://www.fishforecasts.dtu.dk/forecasts/bluefin_tuna_feeding_habitat

ToR f) Joint activities with PICES WG-CEP

During the past year, WGS2D has continued to strengthen the link with its sister group in PICES, Working Group 40: Climate and Ecosystem Prediction (WG-CEP). This collaboration has already provided to be successful, and lead to a theme session co-sponsored by ICES WGS2D and PICES WG-CEP at the Fourth International Symposium on the Effects of Climate Change on the World's Oceans, held in Washington DC in June this year. The session was well subscribed, with 38 abstracts submitted, of which there was space for 16 talks, plus a similar number of posters. The theme session plenary was given by Lisa Goddard, from the International Research Institute for Climate and Society, Columbia

University, USA, with a talk on "Ten-years out: Navigating the information gap between El Niño and climate change". The theme session was then opened by Katherine Mills (Gulf of Maine Research Institute, Portland, ME, USA), with a talk on "Understanding stakeholder decisions to guide forecasting efforts", followed by a further 15 talks.The session was well attended, and the organisers received positive feedback from both the conference organisers and the attendees: in particular, the recent development of oceanographic and ecological forecasting was highlighted as one of the key messages of the conference.

Figure 2. Cartoon from ECCWO conference summarising the main message of the WGS2D sponsored plenary delivered by Lisa Goddard.

WG-CEP and WGS2D have continued to maintain a close link following the conference. Mike Jacox, the chair of WG-CEP was able to present the group to the annual WGS2D meeting this year via Skype, and this formed a very useful basis for discussing similarities and differences between the groups, and the potential for future collaborations. The idea of holding a joint meeting between the two groups has been mooted in the past: however, it was decided to wait with this, as both groups are still in the process of establishing themselves.

Mark Payne, as chair of WGS2D, also presented via Skype to the annual WG-CEP meeting on October 26 2018. This provided to be particularly useful to the WG-CEP to get a broader overview our group, and lead to useful interactions between the groups.

WG-CEP and WGS2D will continue to collaborate and coordinate their activities in the future

The ICES Prediction Cup 2019. An outcome of the 2018 WGS2D meeting was the idea of "crowdsourcing" forecasts from within the ICES community. Forecasting competitions are commonly seen in many other fields, where they play an important role in both producing forecasts, and in improving the understanding of the system being studied and how to forecast it. WGS2D has been inspired by these ideas and has therefore agreed to develop such a concept within ICES. As the "kick-off" for this activity, a networking activity has been proposed for the ICES ASC in 2019, which has been subsequently accepted by ICES. Details of this proposal are in Annex 3. Briefly, the goal is for the ICES community to produce forecasts of an anonymised fish stock in a competitive and time-limited setting (over beer), similar to a hackathon. Withheld data will then be used to judge which model has performed the best, and prizes awarded. It is expected that a scientific manuscript comparing the results of this exercise and the lessons learned will be prepared by WGS2D.

6 Revisions to the work plan and justification

No revisions to the work plan were deemed necessary at this stage.

7 Next meetings

The next meeting will be held at ICES Headquarters, Copenhagen, Denmark, 26–30 August 2019.

While the group has grown in size from last year, and now numbers around 10 members, new members and case studies are still needed to ensure its viability.

8 References

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Annex 1: List of participants

Name	Institute	Email
Mark R. Payne (Chair)	DTU-Aqua Technical University of Denmark 2800 Kgs. Lyngby Denmark	mpay@aqua.dtu.dk
Martin Lindegren	DTU-Aqua Technical University of Denmark 2800 Kgs. Lyngby Denmark	mli@aqua.dtu.dk
Sevrine Sailley	Plymouth Marine Laboratory Prospect Place Plymouth, PL1 3DH United Kingdom	sesa@pml.ac.uk
Anna K. Miesner (by correspondence)	DTU-Aqua Technical University of Denmark 2800 Kgs. Lyngby Denmark	amie@aqua.dtu.dk
Nikolaos Nikolioudakis	Institute of Marine Research Nordnesgaten 33, Bergen Norway	nikolaos.nikolioudakis@hi.no
Susana Garrido	Portuguese Institute of Sea and Atmosphere (IPMA) Rua Alfredo Magalhães Ramalho 6, Lisboa, Portugal	susana.garrido@ipma.pt
Jennifer Devine	Institute of Marine Research Nordnesgaten 33, Bergen Norway	jennifer.devine@hi.no
Ryan McGeady	Department of Zoology, School of Natural Sciences, NUI Galway, University road, Galway, Ireland	r.mcgeady1@nuigalway.ie
Anne Britt Sandø	Institute of Marine Research Strandgaten 196 , Bergen Norway	anne.britt.sando@hi.no
Robin Boyd	University of Reading, Whiteknights PO Box 217 Reading Berkshire RG6 6AH United Kingdom	r.boyd@pgr.reading.ac.uk
Ole Henriksen	DTU-Aqua Technical University of Denmark 2800 Kgs. Lyngby Denmark	ohen@aqua.dtu.dk

Annex 2: Recommendations

Outgoing Recommendations

RECOMMENDATION	ADRESSED TO
WGS2D requests feedback from WGIPS regarding the value, or lack thereof, of the Blue Whiting Spawning Habitat forecast product (see e.g. http://www.fishforecasts.dtu.dk/forecasts/blue-whiting-spawning-habitat for the most recent version). In particular, we would welcome comments on the perceived accuracy and precision of the forecast, timeliness, understandability, presentation format and suggestions for improvement. WGS2D welcomes all critiques of this work (both positive and negative) and would like to encourage the group to actively collaborate to help improve this forecast system.	WGIPS
WGS2D requests feedback from WGINOSE and WGEAWESS regarding the usefulness, or otherwise of the data, provided in response to their requests	WGINOSE, WGEAWESS

Recommendations received and addressed by WGS2D in 2018

Recommended by	Recommendation
WGMEGS (Working Group on Mackerel and Horse Mackerel Egg Surveys) **Chairs:** Gersom Costas, Matthias Kloppmann	WGMEGS recommends that the niche modelling work that was initiated prior to the 2016 MEGS survey and predicts mackerel spawning in space and time is resumed and further progressed. The group expects that the model predicts the spatial and temporal distribution of mackerel egg abundance across the entire mackerel egg survey area at a spatial resolution of the survey grid, i.e. half ICES rectangle. The development of the model should help to improve survey planning and execution. Model output results should be made available for coming surveys prior to the planning meetings. Also, during surveys, refined model results based on recently collected egg data shall be made available to assist survey execution.
	Reply: WGS2D has considered the request and performed analyses examining the predictability of mackerel egg abundance, based on environmental parameters. Unfortunately, based on our analysis and work published in the literature we have not been able to find a sufficiently strong relationship to allow development of a reliable forecast product. Details of the analysis are provided in Annex 2 of the 2018 WGS2D report. WGS2D remains interested in this topic and would welcome input from WGMEGS about how to proceed, with a view towards supporting the 2022 MEGS survey.

WGEAWESS (Working Group on Ecosystem Assessment of Western European Shelf Seas) **Chairs**: Steven Beggs, Eider Andonegi	Request a generation of time-series for temperature (for example) both for the near term and the long term for our area to start exploring about the implications of accounting for them in our future scenarios.	
	Reply: WGS2D was unable to address this recommendation during this years meeting due to time and workforce limitations. However, we recommend that WGEAWESS reviews the outputs provided to WGINOSE, to assess whether such data could also be useful for WGEAWESS.	
WGINOSE (Working Group on Integrated Assessments of the North Sea) **Chairs:** Erik Olsen, Andrew Kenny	WGINOSE requests that WGS2D generate a time-series of SST (other parameters e.g. nutrients) for the North Sea out to 2050.	
	Reply: WGS2D has addressed this request and provided outputs. Details of the analysis are included in Annex 2 of the WGS2D 2018 report.	

Detailed Reply to Request from WGMEGS Working Group

There are a number of publications in the scientific literature which has examined the relationship between the spawning distribution of mackerel along the European shelf edge, and the physical / biological environment (Augustin, Borchers, Clarke, Buckland, & Walsh, 1998; Bruge, Alvarez, Fontán, Cotano, & Chust, 2016; Brunel, van Damme, Samson, & Dickey-Collas, 2018; Hughes, Dransfeld, & Johnson, 2014). Unfortunately, these papers generally show a weak link to the physical or biological environment, with relatively poor explanatory values.

This question has also been address previously with a view to prediction in unpublished work by Mark Payne. These results were WGMEGS in 2015 and are archived today on a YouTube video of the presentation: https://www.youtube.com/watch?v=EVImJz_pohE&t=8s While this model was able to capture some of the main characteristics of the distribution, it's predictive ability was generally poor and could not account for the large interannual variations in distribution seen between years.

This work has been subsequently updated in 2017, by incorporating experimental variables under development for the Copernicus Marine Environmental Monitoring Service (CMEMS). These modelled abundances of micronekton could potentially be used as a proxy for Mackerel food. Further developments to the model also incorporated the use of machine learning techniques to charctertise the relationship between Mackerel spawning activity and their environment.

Incorporating the micronekton variables improves the skill of these models to distinguish between presence and absence of mackerel eggs, relative to the baseline models. There is a clear increase in skill moving from the "baseline" to "baseline+NPP" to models incorporating micronekton variables, indicating that these models are being improved by the addition of these variables. Furthermore, the potential biomass during the day ("pb_day" variable) is consistently the best performing of these micronekton variables. Finally, the difference between the micronekton models used as sources of this data appears to be relatively minor compared to the differences due to changes in the explanatory variables.

Comparable results can be seen for the skill of the egg-production regression models (Figure 4). Model performance approaches a coefficient of determination of up to 50%: importantly, adding micronekton products leads to an increase in this metric from around 38% to 46%. The mean-squared error of prediction is relatively high, however, (corresponding to a mean prediction error of 2 EP units on a logarithmic-scale).

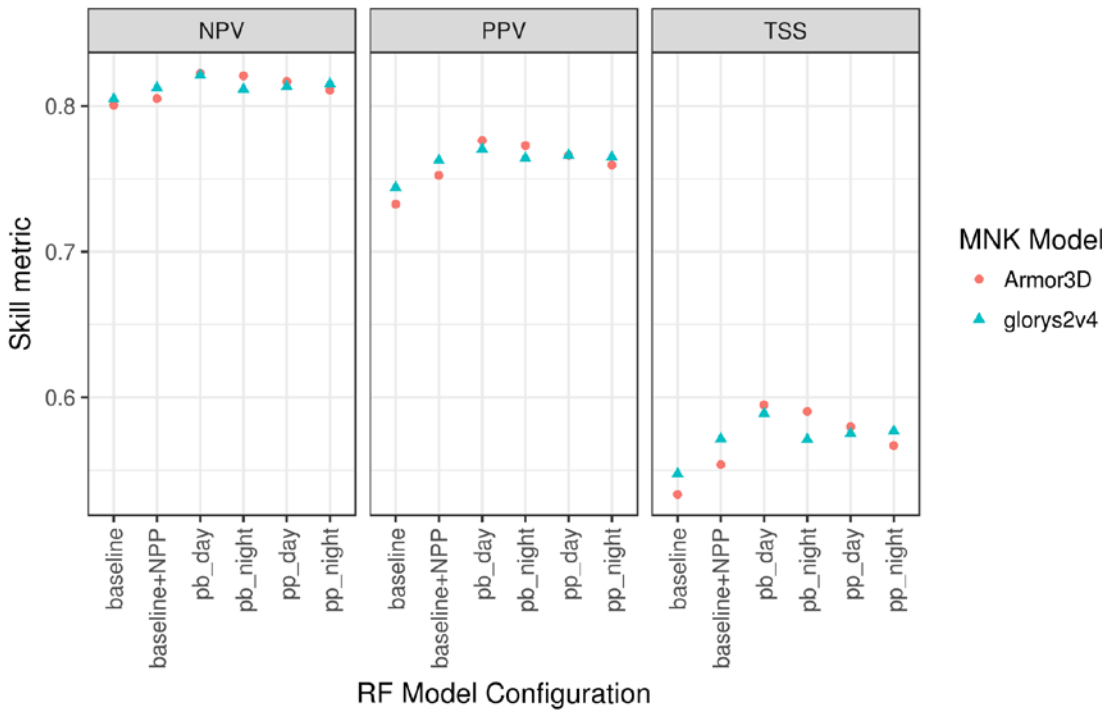

Figure 3. Skill of Random Forest Presence-Absence models. The various model configurations are plotting on the horizontal axis, with the two baseline models at the left of the panel. "pb" indicates potential biomass whilst "pp" indicates potential production of micronekton for both day and night time. Coloured points correspond to the two main micronekton models considered based on the ARMOR3D and GLORYS2V4 reanalysis products. The individual panels correspond to the skill metrics considered: NPV (negative predictive value), PPV (Positive predictive value) and TSS (True-skill score). Higher values of each skill metric indicate greater predictive skill.

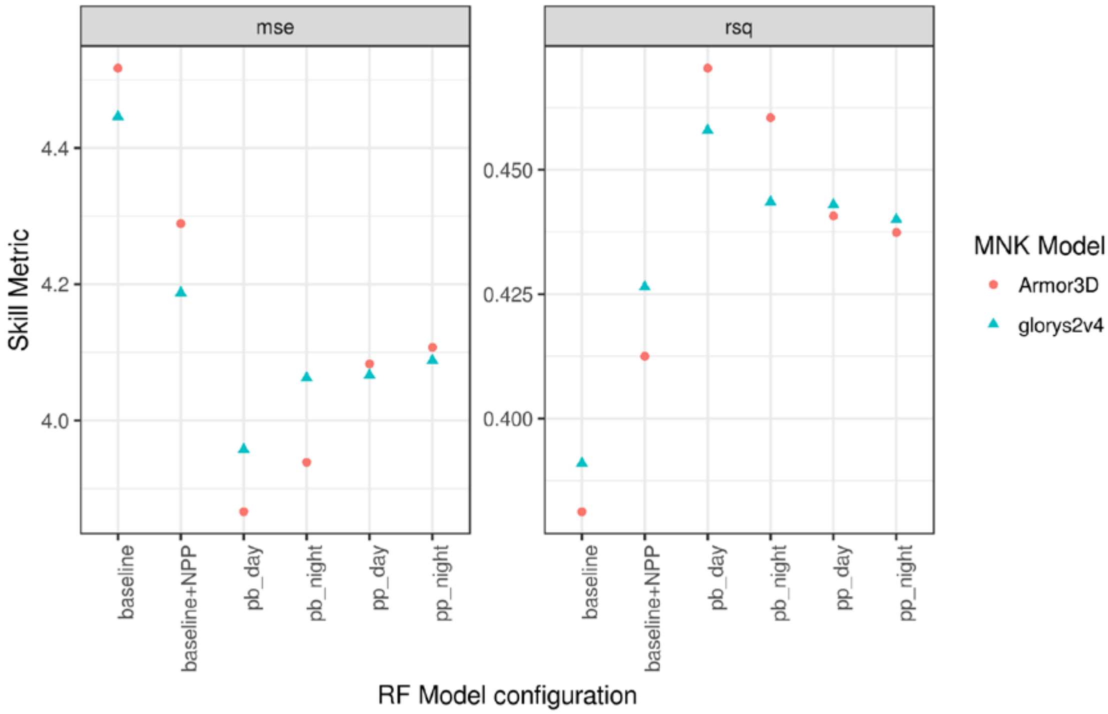

Figure 4. Skill of Random Forest Egg-production regression models. The various model configurations are plotting on the horizontal axis, with the two baseline models at the left of the panel. "pb" indicates potential biomass whilst "pp" indicates potential production of micronekton for both day and night time. Coloured points correspond to the two main GREENUP micronekton models considered, the ARMOR3D and GLORYS2V4 reanalyses. The individual panels correspond to the skill metrics considered: mse (Mean squared error), rsq (coefficient of determination). More skilful models have higher values of rsq and lower values of mse.

In conclusion, it appears that adding micronekton as an explanatory variable does improve the ability of the modelling system to represent both presence-absence and abundance of mackerel eggs. However, the overall quality of the forecasts is generally poor and it seems unlikely that the model can provide a useful forecast product in its current form.

In response to WGMEGs request, WGS2D explored the issue again, this time using a different modelling approach. WGMEGS has previously suggested incorporating spatial and temporal correlation into the model, as a way to reduce the effect of correlations between neighbouring values. While this is a technically challenging task, tools developed within the last few years now make this possible. WGS2D therefore explored this possibility again in the 2018 meeting.

Modelling was attempted utilizing the Tweedie distribution as the observation error, which is actually a family of distributions that are a subset of Exponential Dispersion Models (EDMs), and allows for concurrent consideration of zero values and strictly positive values. To perform this kind of analysis we used the Template Model Builder R package.

The model considered assumed $Y(\mathbf{s})$ to be the observed EP at location $\mathbf{s}$. Moreover, Y was assumed to be Tweedie distributed:

$$Y(\mathbf{s}) \sim Tweedie(\mu(\mathbf{s}), \varphi\mu^{p}) \quad (1)$$

, where

$$\mu(\mathbf{s}) = \beta_0 + f(X) + \delta(\mathbf{s}) \quad (2)$$

Here b_0 is the intercept, $f(X)$ is a continuous function of a covariates vector X modelled with P-splines, and δ is a zero-mean spatial Gaussian random field with Matern covariance structure.

The exploratory analysis revealed that the data, unfortunately, include erroneous values that can have a significant effect on the results (e.g. bottom depths of 8 meters in certain stations). This means that the data needs tidying up before it is ready for any robust analysis, and this is a process that can be undertaken only with scientists that are well aware of the nature of the data (e.g. those participating in the WGMEGS).

As a result, WGS2D cannot provide a forecast for WGMEGS at the current stage. Some preliminary modelling work carried out, yielded very poor fits, partially stemming from the 'non-clean' data and the lack of explanatory covariates with strong signal on the response variable (EP). For the current case study bottom depth and sea surface temperature were explored as covariates. For simplicity we also assumed independence between years and treated data from each survey as pooled, i.e. not in separate sampling periods. In most cases, the models did not converge because of the characteristics of the datasets and whenever they did converge, the results were not trustworthy.

WGS2D is interested in continuing the modelling efforts on this specific dataset and will work towards the direction of preparing a full modelling report with forecasts to be presented in the next meeting of WGS2D.

Detailed Reply to Requests from WGINOSE and WGEAWESS

WGS2D received a request from the working group on Integrated Assessments of the North Sea (WGINOSE) to produce forecasts of Sea Surface Temperature (SST) in the North Sea. We were asked to generate separate time-series for each of the strata shown in Figure 5 out to 2050. We have provided raw monthly averages for each strata from three Earth System Models (ESMs) out to 2100. The ESMs used were the Community Earth System Model, the Max Plank Institute Earth System Model, and the Norwegian Earth system Model. All forecasts were generated under the RCP 8.5 scenario, and are summarised in terms of annual averages for each strata in Figure 6

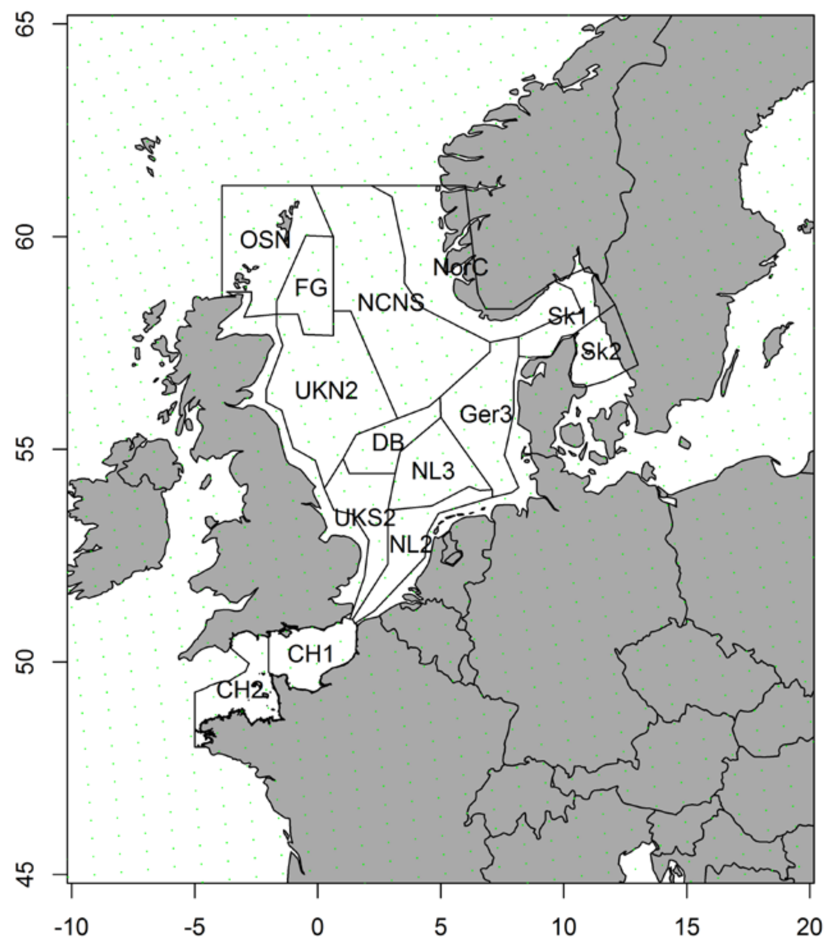

Figure 5. North Sea strata as defined by WGINOSE: OSN = Orkney Shetland, CH1 = channel east, CH2 = channel west, NL2 = Netherlands nearshore, UKN2 = UK north offshore, DB = Dogger Bank, NL3 = Netherlands offshore, FG = Fladen Ground, NCNS = Northern central, NorC.

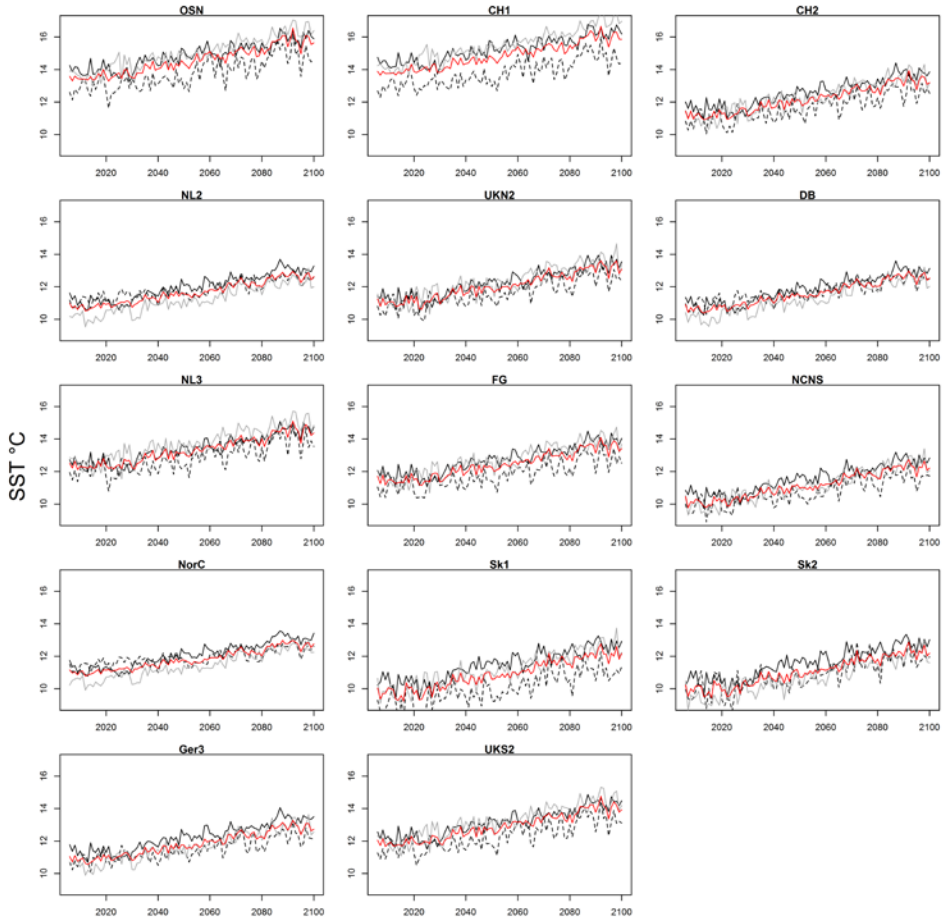

Figure 6. Projections of Sea Surface Temperature (SST) for each of the North Sea strata in Fig. from three Earth System Models: 1) the Community Earth System Model (solid black line); 2) Max Plank Institute model (dashed line); and 3) the Norwegian Earth System Model (grey line). Red lines show mean SST across models. All projections were generated under the RCP 8.5 scenario.

Annex 3: Proposal for a networking session at ICES ASC 2019

Select ASC session type *

Network session

Short Title

The ICES Prediction Cup 2019

Session convener 1 (contact person) - Name (required) *

Mark R. Payne

Session convener 1 (contact person) - institute address and country *

Technical University of Denmark (DTU-Aqua)
2800 Kgs. Lyngby
Denmark

Session convener 1 (contact person) - email *

mpay@aqua.dtu.dk

Session convener 1 (contact person) - telephone *

+45 35883422

Session convener 2 - Name (required) *

Sevrine Sailley

Session convener 2 - Email *

sesa@pml.ac.uk

Description *

Can we make reliable predictions of fish stocks? The ICES Prediction Cup is an event intended to both answer this important scientific and practical question, and to have fun at the same time.

Participants in the Cup will compete, either individually or in teams, against each other to analyse supplied datasets of real fish stocks, with the aim of forecasting withheld data. The results that they generate will then be compared by the convenors against the truth, and the team that produces the most reliable forecasts will be crowned the ICES Prediction Champion for 2019.

While this is intended to be a fun social event, it has a serious scientific motivation at its core. In spite of a century of trying, fisheries scientists have yet to develop regular and reliable predictive skill. However, while we have not been able to predict fish stocks in the past, that does not mean that it is impossible. Improvements in the ability to observe and forecast the ocean in recent years, together with the availability of new tools, mean that the scientific landscape today is very different from that in which many of the pioneers of the field worked. Nevertheless, much work remains to both take advantage of these new advances and raise awareness within the community of these new capabilities.

The ICES Prediction Cup addresses these issues in a fun way. The Cup aims to explore the variety of approaches that can be used to generate predictions by crowdsourcing forecasts based on a common, standardised data set. At the same time, the exercise of making and evaluating predictions will serve to highlight this predictive potential amongst participants. Furthermore, the variability in the approach of the modeller and how that might influence the answer is of interest. The ICES Prediction Cup is intended to be the launch event publicising a broader prediction competition that will be run by WGS2D, the Working Group on Seasonal-to-Decadal Prediction of Marine Ecosystems. The results will be written up as a scientific publication, with all participants invited to contribute as authors. Furthermore, the most successful models will be operationalised by ICES WGS2D and provided as regular forecasts to the relevant assessment working groups.

(250-400 words)

Session teaser *

For more than a century, marine scientists have tried to forecast fish stocks with little success. But today our ability to observe and forecast the ocean is unparalleled. Can the ICES community turn this data into reliable forecasts of fish stocks? At the 2019 ASC, the ICES Prediction Cup will test if this can be done and crown the first ICES Prediction Champion.

(<75 words)

Tweet text *

They say you can't predict fish stocks. Prove them wrong! Compete in the #ICESPredictionCup against your colleagues, do innovative science, improve stock assessment and most importantly, have fun and WIN PRIZES and FAME! [Tuesday] night at #ICESASC2019!

(<280 characters)

Suggested theme session format *

Informal and fun event involving beer, coding and teamwork, ideally run as an evening social event.

a) Short introductory presentation explaining the concept of the Prediction Cup, the rules and what it takes to win

b) Revelation and distribution of datasets to predict

c) 1 hour to work on the model and predictions

d) Presentation of results

e) Awards ceremony

Total running time: 2 hours

(<100 words)

Expected participation *

The event is intended to attract a wide range of people from across the ICES community, from within both the Science and Advisory communities. Importantly, it is intended to be open to all, and does not require either advanced statistics or any biological knowledge: use of excel is sufficient.

(<100 words)

Links to the seven ICES science priority areas as proposed by the Science Committee (see link to codes above) *

x Food from the sea (Code 1)

x Understanding ecosystems (Code 2)

Impacts of human activities (Code 3)

Observation and exploration (Code 4)

x Emerging techniques and technologies (Code 5)

Conservation and management (Code 6)

Sea and society (Code 7)

Links to ICES Steering Groups and/or Advisory Committee *

Aquaculture Steering Group

x Ecosystem Observation Steering Group

x Ecosystem Processes and Dynamics Steering Group

Human Activities, Pressures and Impacts Steering Group

Integrated Ecosystem Assessments Steering Group

x Advisory Committee

Links to ICES Strategic Initiatives (if relevant)

x ICES-PICES Strategic Initiative on Climate Change Impacts on Marine Ecosystems

Strategic Initiative on the Human Dimension

Annex 4: Blue whiting spawning habitat forecast 2019

ICES WGS2D Forecast sheet 01-20180831
Issued 31-08-2018. Valid through to 01-06-2019.

Prepared by Mark R. Payne, DTU Aqua, Copenhagen, Denmark. Reviewed by members of ICES WGS2D. This is the first forecast for the 2019 spawning season. The next update is planned on or before 1 November 2018.

1. Forecast

The spawning distribution for March 2019 is expected to be highly compressed against the continental shelf edge, reflecting the continuing current unusual oceanographic conditions in the region Minimal spawning on or to the west of Rockall Plateau is expected (Figure 1). In historical terms, the westward extent of spawning is forecast to be among the lowest since 1950, and the spawning area also low (Figure 2).

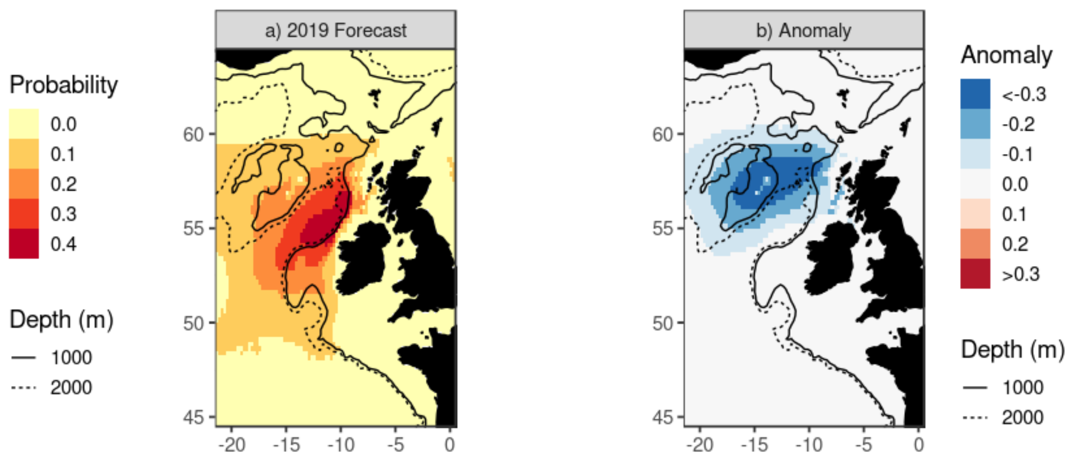

Figure 1. Forecast spawning distribution for blue whiting in March 2019. Distribution is represented here as the probability of observing blue whiting larvae in a single haul performed by the Continuous Plankton Recorder and is plotted as a) the value and b) the anomaly relative to the climatological probability (1960-2010). Probabilities > 0.4 can be considered as the core spawning habitat. The 1000m and 2000m isobaths are added for reference.

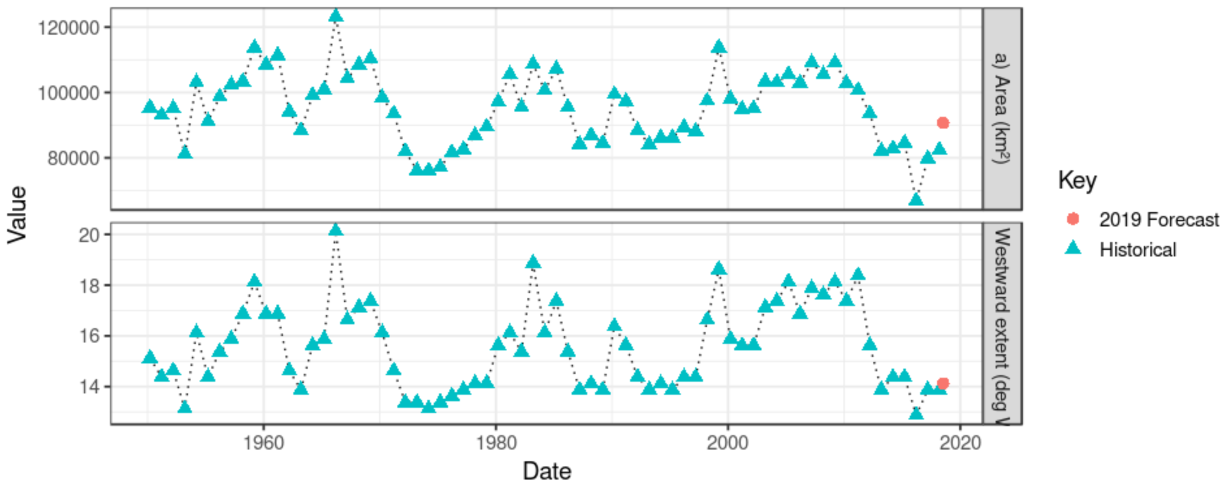

Figure 2. Time-series of core spawning area characteristics. a) Area (km²) of core spawning area of blue whiting in the month of peak spawning (March). b) Westward extent (degrees of Longitude W) of core spawning area. Historical (blue triangles) and forecast (orange dot) values are shown.

2. Background

The spawning distribution of blue whiting has varied in the past and has expanded, contracted and shifted locations (Figures 2, 3). The dominant feature of these changes is a westward expansion away from the shelf-break region west of the north-west European continental shelf onto the Rockall plateau and Hatton bank region (Figure 3).

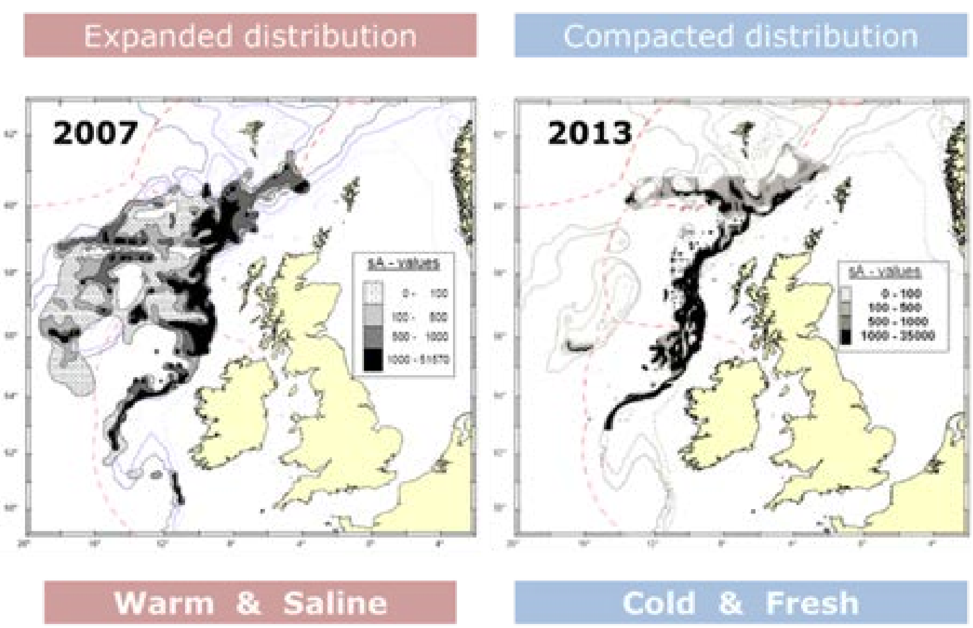

Figure 3. Spatial distributions of blue whiting from the International Blue Whiting Spawning Stock Survey Two years characterized by different oceanographic conditions (2007 and 2013) are shown. Note the large difference in range occupied towards the west in 2007 compared to 2013.

Shifts in the spawning distribution of blue whiting have been linked to oceanographic conditions in this region (Hatun *et al.* 2009), and in particular to the salinity in the region (Miesner and Payne 2018). Spawning typically occurs within a narrow salinity window between approximately 35.3 and 35.5 (Figure 4). Salinity in this region is strongly driven in turn by the dynamics of the North Atlantic sub-polar Gyre (Hatun *et al.* 2005). The slow dynamics of oceanographic properties can be used to provide reliable estimates of future distributions of water masses and thereby spawning habitat for blue whiting.

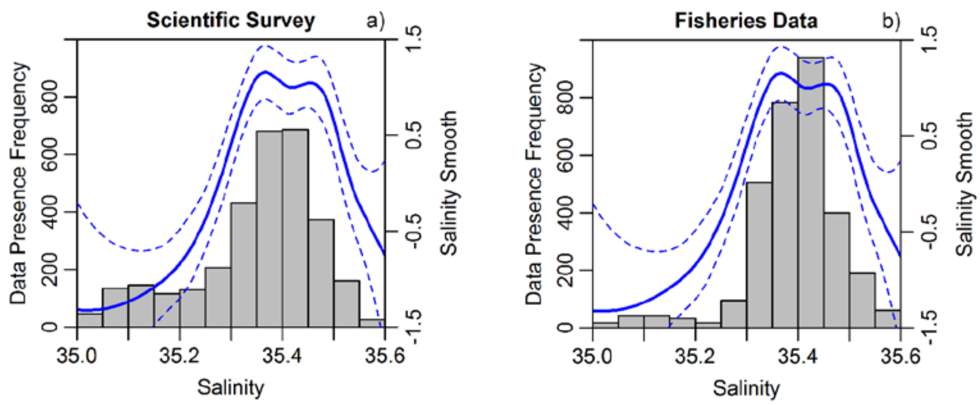

Figure 4. Relationship between spawning and salinity from independent data sources Presence frequency of spawning blue whiting (number of pixels with presences) a) observed in scientific surveys and b) caught in fisheries is compared to the salinity (250–600 m) at which these observations were made (bars). The blue line indicates the modelled smooth function of blue whiting larval-presence obtained from the Species Distribution Model (SDM) based on larval blue whiting catches by the CPR survey, with dashed lines indicating the standard error. Panel a) shows observations from late March/ early April, and Panel b) data shows data from March.

3. Basis for Forecast

Table 1. Overview of the basis for the forecast.

Component	Description
Biological model	Species distribution model (GAM) using salinity, latitude, day-of-year, solar elevation, and depth. Model is parameterised against observations of Blue Whiting larvae from the continuous plankton recorder (CPR) between 1951 and 2005.
Environmental data set(s)	1. EN v4.2.1: an optimal interpolation of oceanographic profiles onto a 1x1 degree, monthly grid from 1900-present (Good *et al*. 2013) 2. PSY4 v3.1: a model-based reanalysis with assimilation of profile and satellite data, on a 1/12 x 1/12 degree grid, used here as a monthly product, from 2007-present. Copernicus CMEMS product id: GLOBAL_ANALYSIS_FORECAST_PHY_001_024_MONTHLY
Environmental variables	Salinity averaged over 250–600m depth on a pixel-by-pixel basis
Environmental forecast method	Persistence from the most recent data product (July 2018)
Forecast lead time	Eight months (From July 2018 to March 2019)

This forecast is based on a species distribution model developed by Miesner and Payne (2018). The model uses observations of blue whiting larvae captured in the Continuous Plankton Recorder (CPR) as a response variable and links their presence to environmental covariates as explanatory variables, including salinity at spawning depth (300–600m), latitude, day of year, solar elevation angle and bathymetry. Salinity at spawning depth was shown to be the most important environmental factor that varied inter-annually, and drives the westward expansion of spawning habitat. The model has been verified by cross-validation with the CPR observations. Furthermore, the sensitivity of the larval response to salinity obtained from CPR data shows good agreement with independent distribution data sets obtained from both commercial fishers and scientific surveys (Figure 4).

Forecasts of the physical environment (and specifically salinity at spawning depth) are derived by assuming that the most recently observed state of the environment will persist until at least the next spawning period and possibly beyond.

4. Quality Considerations

This forecast is a prediction of the potential spawning habitat of the species, and should not be interpreted as a direct forecast of distribution. While there is a relationship between the two, it is important to remember that the actual distribution of spawning may not utilise all of the potential spawning habitat (e.g. due to migration dynamics, density-dependent processes or other biotic factors). On the other hand, it is unlikely that spawning can occur in the absence of suitable habitat. The ability of this forecast to represent distribution is therefore asymmetrical.

Forecasts of the physical environment in this region are currently based on persistence i.e. the assumption that, for example, next year will be the same as this year. While the dynamics in this region are typically slow, they have occasionally moved rapidly, which could cause discrepancies between forecasted and observed spawning habitat. However, such events are considered relatively rare and analysis of the forecast skill has shown that this is a valid assumption.

5. Forecast Skill Assessment

Forecast skill was assessed using historical data independent of those used in model development, for different time lags. The skill based on persistence is significant for forecast lead-times up to 2-3 years (Figure 5).

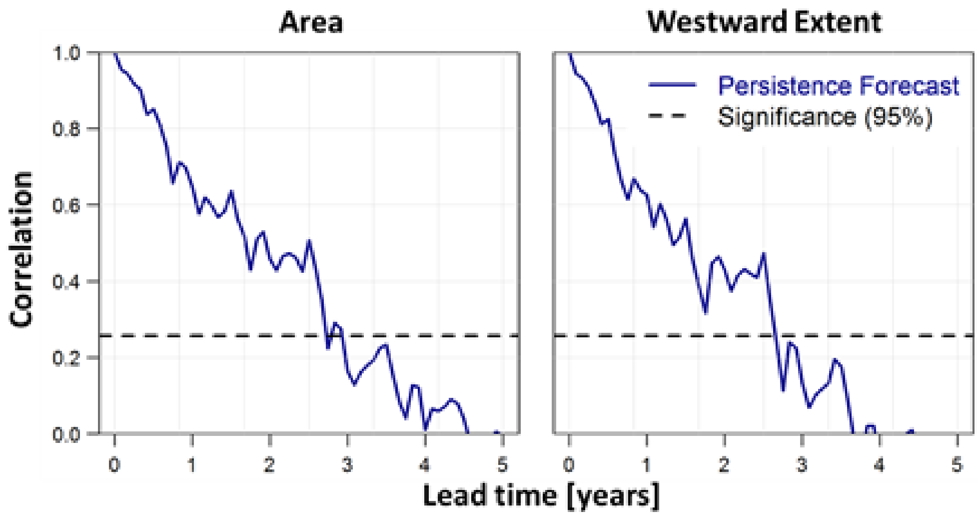

Figure 5. Forecast skill assessment Forecast skill is shown for a) the area (km²) and b) westward extent of potential spawning area for blue whiting in the waters west of the northwest European continental shelf. The plots show correlation based on persistence of ocean dynamics for various lead times into the future. The dashed line indicates the minimum significant correlation (P > 0.05).

6. For More Information

For more information, contact Mark R. Payne, DTU-Aqua, http://www.staff.dtu.dk/mpay. The latest version of this and other forecasts can be found on the website fishforecasts.dtu.dk Code used to generate this forecast is available from the WGS2D GitHub repository, https://github.com/ices-eg/wg_WGS2D in the directory "01_Blue_whiting_spawning_distribution".

7. Acknowledgements

The research leading to these results has received funding from the European Union 7th Framework Programme (FP7 2007–2013) under grant agreement number 308299 (NACLIM) and the Horizon 2020 research and innovation programme under grant agreement number 727852 (Blue-Action). We thank Åge Høines and the members of the WGIPS group responsible for planning the IBWSS survey for input.

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9. Change Log

- 20180831 Updated to 2019 forecast.
- 20180301.v03.0 Updated EN4 data set to 4.2.1. Added forecast expressed as an anomaly. Added "forecast basis" summary table. Added supplementary information comparing with survey track and current oceanographic state. Add PSY4 reanalysis product into mix.
- 20180117.v02.1 Minor update to include salinity contours in Figure 2.
- 20180115.v02 Updated to October 2017 oceanography. Visual improvements.
- 20170614.v01 Initial draft version

10. Supplementary Information

S1. Oceanographic Conditions

To provide a more detailed insight into the current oceanographic conditions driving the distribution, the current state of salinity at the spawning depth is shown below, as of July 2018. In particular, the well-reported salinity anomalies in the North Atlantic sub-polar gyre (upper-left side of panel b) are having a clear effect on the spawning region of blue whiting and compressing the spawning habitat.

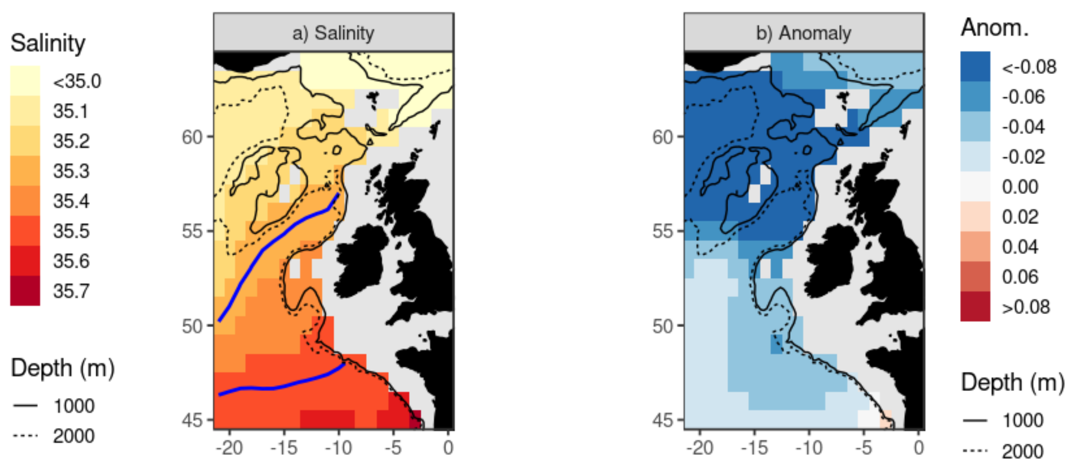

Figure S1.1 Observed salinity distribution and associated anomaly in the spawning region. Salinity is based on the EN4 observational dataset for January 2018 at spawning depth (250–600m) and is plotted as a) the absolute value and b) the deviation from the annual climatology (1960–2010). The isohalines defining the suitable salinity window (35.3–35.5) at spawning depth for Blue Whiting are marked with a blue contour line in panel a). The 1000m and 2000m isobaths are added for reference.

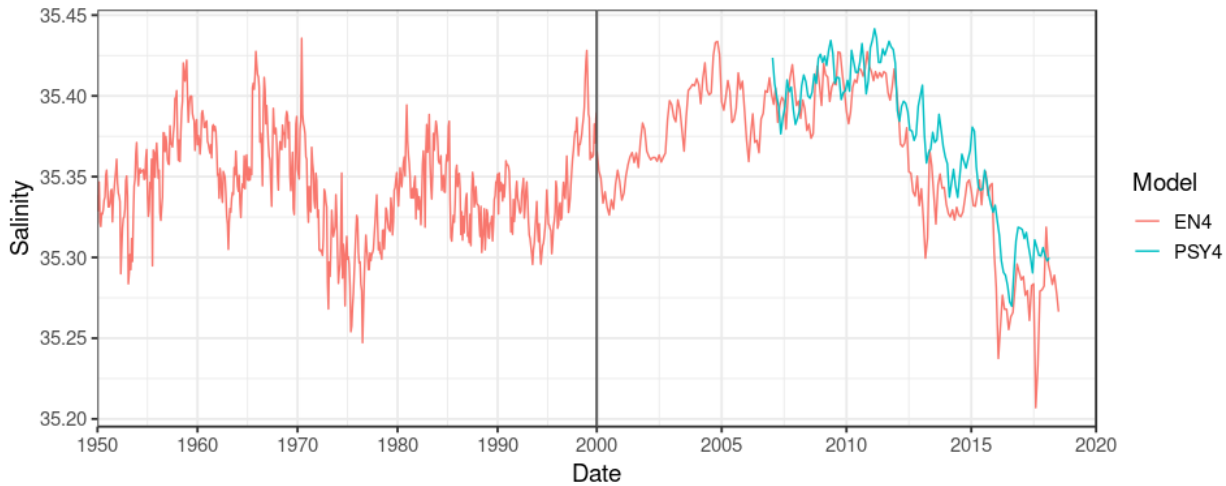

Figure S1.2. Time-series of salinity in the spawning area. Monthly salinity at spawning depth (250–600m) from the EN4 and PSY4 datasets are plotted as a function of time - note the change in timescale at 2000, to give greater resolution of the most recent years.

11. License Information

Annex 5: Bluefin Tuna Feeding Habitat Forecast, 2019

ICES WGS2D Forecast sheet 02-20180917
Issued 17-09-2018. Valid through to 31-08-2019.

Prepared by Mark R. Payne, DTU Aqua, Copenhagen, Denmark
This is the first forecast for the 2019 feeding season. The next update is planned on or before 15 October 2018.

1. Forecast

All forecast models suggest the absence of suitable habitat for bluefin tuna in the Denmark strait region in August 2019 (Figure 1): however, the models forecast expanded habitat around the Rekyjanes ridge area and in the central Norwegian sea when compared to the long-term mean. The total area of thermally suitable habitat in this region will be lower than the peaks seen in 2010 and 2012 (Figure 2), although the amount of habitat is expected to remain above that seen prior to the mid-1990s.

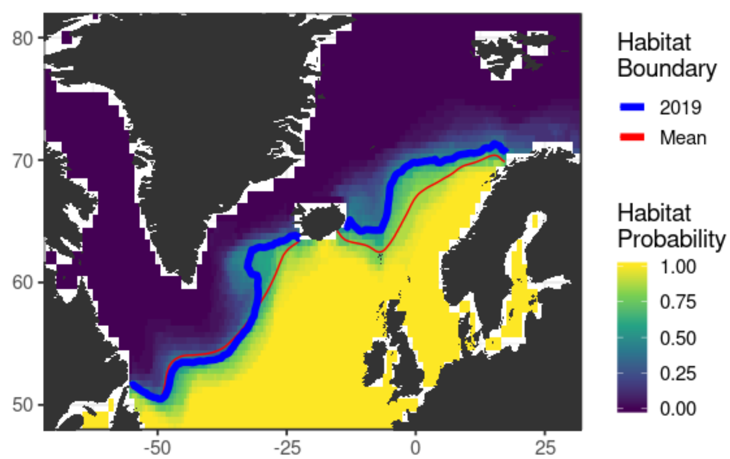

Figure 1. Probability of a given region being thermally suitable feeding habitat for bluefin tuna in August 2019. For each pixel, the probability of the sea surface temperatures being thermally suitable for Atlantic bluefin tuna (i.e. above 11 degree C) is estimated from the North American Multi-Model Ensemble (NMME). The contour line corresponding to a probability of 0.5, which has been used here to define the most likely limit of suitabe habitat, is plotted as a heavy blue line, while the average habitat boundary (1983–2005) is plotted with a red line. All regions south and east of these lines are classified as suitable habitat.

Figure 2. Time-series of the area of suitable habitat. Interannual variability in the area of water warmer than 11°C during August in the Denmark Strait – Irminger Sea area east of Greenland is plotted from 1960–2020. The area of water >11 °C was estimated within the region 55–70°N and 50 –10 °W (see Figure 3). In addition, the plot also shows the forecast area of habitat for August 2019 based on the forecasts from North America Multi-model Ensemble (NMME) shown in Figure 1: the width of the area is related to the density of the predictions, while the heavy red dot is the ensemble mean prediction.

2. Background

An exploratory fishing survey for Atlantic mackerel performed in August 2012 in Denmark strait between Iceland and Greenland captured three individual adult bluefin tuna (*Thynnus thunnus*); (MacKenzie *et al.* 2014). It is believed that this was the first such reported occurrence in this region in at least 370 years, and most likely ever. The tuna were captured in a single net-haul in 9–11º C water together with 6 tonnes of mackerel, which is a preferred prey species and itself a new immigrant to the area (Astthorsson *et al.*, 2012). Regional temperatures in August 2012 were historically high and part of a warming trend since 1985, when temperatures began to rise. As a consequence, the area of relatively warm water (i. e., > 11 C) which could serve as potential habitat in this region has expanded by more than 800 000 km2, an area the size of France (Figure 2). The presence of bluefin tuna in this region is likely due to a combination of these warm temperatures that are physiologically more tolerable and immigration of an important prey species into the region.

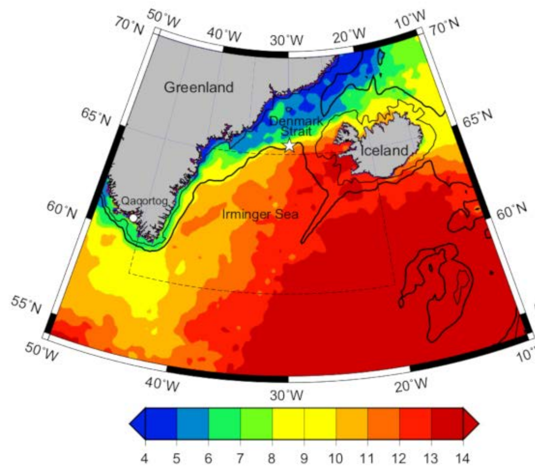

Figure 3. 2012 Observation of bluefin tuna in Denmark strait. Sea surface temperature (SST) based on the Operational Sea Surface Temperature and Sea Ice Analysis (OSTIA) product (Donlon *et al.*, 2012) for August 22, 2012 in the east Greenland-Iceland area of the north Atlantic Ocean. A white star marks the location of the haul (65°420N, 30°500W) which captured three bluefin tuna (Thunnus thynnus) using pelagic fishing gear during exploratory scientifically monitored fishing for mackerel (Scomber scombrus). Depth contours are drawn at 200 m (thin line) and 1000 m (thick line). Reproduced from MacKenzie *et al.* 2014.

Tuna are unique amongst fish in that they have the ability to regulate their body temperature and maintain a body temperature above the ambient water temperature, analogous to the physiological of mammals (although less efficient). The dynamics of this process have been well studied using data storage tags e.g. (Block *et al.*, 2001; Walli *et al.*, 2009) and show that, while feeding bluefin tuna can make forays into extremely cold water (down to 0 deg C), both laterally across fronts and vertically into deep water, they always need water of around 11 deg C or warmer to return to "warm-up" again, especially during the nighttime when they cannot feed. This strict physiological requirement for access to warm "refuge" water ultimately places a constraint on their distribution and mirrors the results derived by other authors (Muhling *et al.*, 2017a, 2017b). Furthermore, given that 1) the surface layers are typically the warmest part of the ocean 2) sea surface temperature (SST) is readily observed from satellite and 3) SST is the most predictable marine variable, this would seem to be well suited for prediction.

3. Basis for Forecast

Table 1. Overview of the basis for the forecast.

Component	Description
Biological model	Threshold of 11 degree C defining the minimum suitable temperature, based on MacKenzie *et al.* 2014 and supported by Muhling *et al.* 2017b.
Environmental data set(s)	HadISST (Rayner *et al.* 2003)
Environmental variables	Sea-surface temperature
Environmental forecast	Outputs from the North American Multi-model Ensemble (NMME) of

method	seasonal forecast models (Kirtman et al)
Forecast lead time	11 months (From September 2018 to August 2019)

4. Quality Considerations

An important point to make in the interpretation of these results is that the skill of these forecasts is inherently asymmetrical in nature. The presence of suitable thermal habitat in a region does not necessarily guarantee that it will be occupied by fish – other processes that are not encapsulated in this analysis, such as the presence of suitable prey, or even the abundance of bluefin tuna itself, can also be limiting, while the peculiarities of migration dynamics can also be important. On the other hand, the absence of suitable thermal habitat does guarantee the absence of fish – if the water is below their cold tolerance bluefin tuna will not enter, regardless of how much prey is present. In this way, our forecasts are essentially asymmetrical in nature – they are much better at predicting absence than presence – and should be interpreted with corresponding care.

Secondly, our yearly estimates of the suitable habitat area (Figure 2) integrate the local spatial variability in temperature that bluefin tuna might detect and perceive when in and near the region. The forecast of the area of suitable habitat (Figure 2) should therefore always be considered in conjunction with the spatial forecast (Figure 1).

5. Forecast Skill Assessment

Forecast skill was assessed using historical data independent of those used in model development, for different time lags. The NMME forecast system outperforms a persistence forecast at lead times beyond approximately three months (Figure 4).

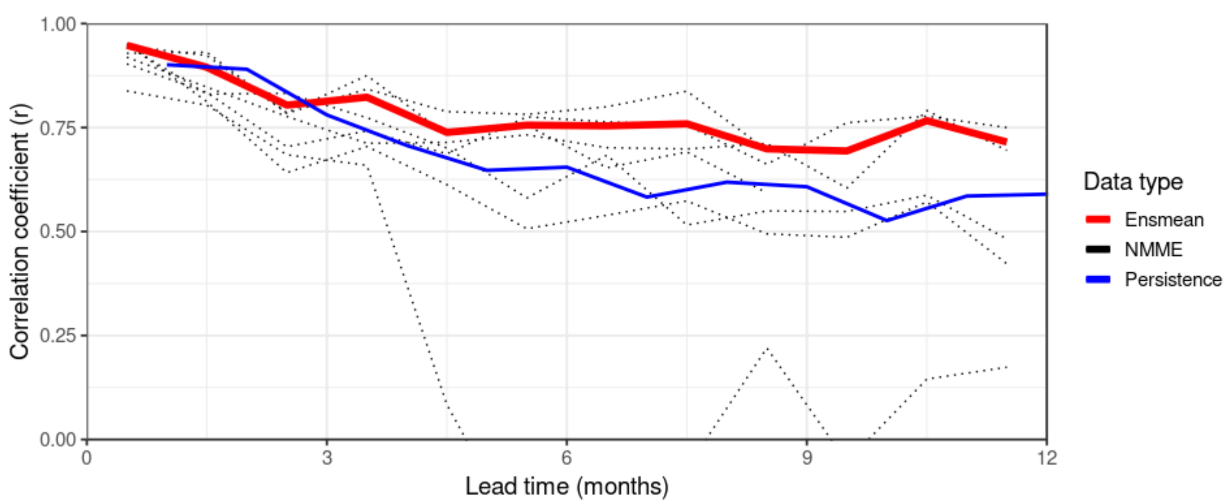

Figure 4. Skill assessment. The skill of the North America Multimodel Ensemble (NMME) in forecasting the area of suitable habitat in the Irminger Sea region as a function of leadtime is assessed. Model skill, represented as the correlation between the forecast and observed area of habitat, is plotted as a function of lead time, in months after the forecast was initialised. Dotted thin lines correspond to the individual components of the NMME, while the heavy read line is the skill of the combined ensemble mean forecast. The persistence forecast (blue line) provides a baseline reference forecast by assuming the observed anomalies will persist.

6. For More Information

For more information, contact Mark R. Payne, DTU-Aqua, http://www.staff.dtu.dk/mpay. The latest version of this and other forecasts can be found on the website fishforecasts.dtu.dk Code used to generate this forecast is available from the WGS2D GitHub repository, https://github.com/ices-eg/wg_WGS2D in the directory "02_Bluefin_tuna_feeding_habitat".

7. References

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8. Change Log

20180917 Initial version

9. License Information

10. Acknowledgements

The research leading to these results has received funding from the European Union 7th Framework Programme (FP7 2007–2013) under grant agreement number 308299 (NACLIM) and the Horizon 2020 research and innovation programme under grant agreement number 727852 (Blue-Action).

Annex 6: ECCWO Theme session details

The following theme session was held at the Fourth International Symposium on the Effects of Climate Change on the World's Oceans in Washington DC, USA, 4–8 June 2018. The session was co-sponsored by groups from ICES (WGS2D) and PICES (WG-CEP).

Session S2: From prediction to projection: the role of seasonal to decadal forecasts in a changing climate

Co-Chairs: Mark R. Payne (ICES WGS2D); (DTU-Aqua, Technical University of Denmark Copenhagen, Denmark), Erica Ombres (NOAA OAR Ocean Acidification Program, USA), Mike Jacox (PICES WG-CEP) (University of California Santa Cruz, Institute of Marine Sciences, NOAA Southwest Fisheries Science Center, USA), Masami Nonaka (PICES WG-CEP) (Japan Agency for Marine-Earth Science and Technology (JAMSTEC), Yokohama, Japan)

Abstract: Research examining the future impacts of environmental change and variability on ocean ecosystems has historically been focused on making projections on multi-decadal to centennial time scales. Nevertheless, recent years have seen the emergence of the first generation of marine ecosystem predictions working on shorter timescales (i.e. seasonal, annual and decadal scales). These forecasts are tailored to the tactical decision-making timescales of individuals, businesses, sectors or governments and inform strategies for coping with and adapting to climate change and variability. They also form a natural continuum with projections on the climatic timescale: many of the techniques used are similar, and testing predictability in the short-term builds confidence in our ability to project in the long-term. In this session, we welcome contributions on a broad range of potential future impacts on ocean ecosystems, including (but not limited to) ocean warming, circulation changes, acidification, eutrophication, hypoxia, and ecosystem structure or function. We seek research that addresses prediction of these ecosystem impacts as well as its relationship to long-term projections; relevant topics include 1) mechanisms that generate predictability in ocean ecosystems, 2) methods for statistically and/or mechanistically forecasting physical and/or biological variables, 3) case studies of existing biological forecast systems, 4) requirements for forecasts - including end-user needs - and assessment of forecast value, and 5) uses of forecasts within a climate-change adaptation context. Contributions that link the time-scales of prediction and projection and highlight examples of what one field can learn from the other are particularly encouraged.

Plenary Presentation

Lisa Goddard (International Research Institute for Climate and Society, Columbia University, USA) - Ten-years out: Navigating the information gap between El Niño and climate change

Invited Speaker

Katherine Mills (Gulf of Maine Research Institute, Portland, ME, USA) - Understanding stakeholder decisions to guide forecasting efforts

Presentations

- Michael Jacox, Mechanisms driving seasonal forecast skill in the California Current System
- Mercedes Pozo Buil, Subsurface dynamics leading to decadal predictability in upwelling systems of the North Pacific
- Antonietta Capotondi, Forecasting physical drivers of marine ecosystems in the California Current System using a Linear Inverse Modelling approach
- Takashi Mochizuki, Subdecadal modulation in the Pacific in 2000s
- Fernando Gonzalez Taboada, Subseasonal forecast of surface water conditions in Chesapeake Bay using a hybrid approach
- Samantha Siedlecki, Seasonal forecasts of hypoxia and ocean acidification in Washington and Oregon waters
- Jong-Yeon Park,Seasonal to multi-annual marine biogeochemical prediction using GFDL's Earth System Model
- Jonathan Tinker, Exploring the potential for a North West European shelf seas ecosystem seasonal forecast
- Jason Hartog, Seasonal and decadal forecast development for a multi-species pelagic longline fishery
- Neda Trifonova, Predicting ecological responses to climate variability with a dynamic Bayesian network model
- Mark Payne, Envisaging the future distribution of North Atlantic bluefin tuna across seasonal, decadal and centennial scales
- Katherine Mills, Seasonal forecasting of Pacific hake distribution in the California Current Ecosystem
- Gavin Fay, Incorporating recruitment-environment linkages into stock assessment models for Alaskan groundfish with application to population projections in a changing climate
- James Thorson, Forecast skill for predicting distribution shifts: A retrospective experiment for marine fishes in the Eastern Bering Sea
- Noah Oppenheim, Forecasting fishery trends in a warming ocean: A modelling framework using early life stages of the American lobster

Annex 7: Science Highlights

Temperature and food-mediated variability of Atlanto-Iberian European sardine populations

Susana Garrido, Alexandra Silva, Vitor Marques, Ivone Figueiredo, Philippe Bryère, Antoine Mangin, A Miguel P. Santos

The influence of environmental drivers on European sardine recruitment strength was investigated in the three recruitment hotspots off Iberia (Biscay, NW Portugal, Gulf of Cadiz). Satellite-derived Sea Surface Temperature (SST) and Chlorophyll-a concentration (Chla) data from the previous spawning seasons (January to March/April and October to December of the previous year) were related to recruitment success data in the main recruitment hotspots. Recruitment data was taken from yearly acoustic scientific cruises and from the ICES recruitment index estimated by an age-structured model for the entire stock. Linear discriminant analysis using SST, Chla and the spawning stock size can discriminate years of high and low recruitment with ≥79% accuracy, generally high recruitment years were associated with high Chla and low SST, although the most important variables to discriminate between the groups were area-specific (Garrido *et al.* 2017). The time-series of available data at the time the indicator was developed was still small, but significant relationships were consistent with field and laboratory studies relating larval growth and mortality with main environmental drivers. Four to five more years of data are now available allowing investigating if the recruitment predictions of the LDA models were accurate. LDA was able to correctly predict recruitment strength in the Bay of Biscay (75% accuracy), but failed for the other two recruitment hotspots, where important ecosystem changes occurred (such as an outburst of anchovy population in the NW representing the historical maximum in the area). The longer database is enabling these relationships to be further investigated, namely using other approaches such as GAM, with the aim of constructing a reliable indicator to predict the level of recruitment with sufficient advance to help in the management of this important fishing resource.

North Sea Saithe

Jennifer Devine

Connectivity of saithe populations are being investigated using a three-pronged approach, including genetic determination, larval connectivity based on biophysical dispersal models, and population spatial models. Saithe were chosen because of the extensive mixing of stocks both at the larval/0-group stage (prior to arrival on near-shore nursery areas) and at the adult stage, when fish are performing extensive feeding migrations. Fish of mixed origins are captured together in the commercial fisheries, the extent of mixing is poorly known, and this has implications for assessment and management. Discussions with fishermen about North Sea saithe behavior during spawning migrations indicated that catches of these populations, particularly North Sea and Northeast Arctic stocks, may be more mixed than previously thought. The scope and preliminary work on this project was presented, but the behavior of saithe during their spawning migrations and its impact on a North Sea spawning saithe acoustic survey was also presented as a potential "low hanging fruit" that the working group could work on as a spawning distribution forecast object.

The spawning saithe survey currently covers only the shelf edge. In abnormal years, fish appear in an area further up on the shelf, outside of the survey area. There is a need to know when an abnormal year may occur (and what drives abnormal years) for survey planning. Adding this additional area to the survey every year, when not needed, would significantly increase survey time and costs, therefore predicting when an additional strata is needed would assist planning and decrease variability in spawning biomass estimates.

Fish projection: approach in CERES and C3S–MCF

Severin Sailley

CERES is a large European project, and C3S-MCF a Copernicus Climate Change Services funded project. Both approach the question of projection of fish biomass and distribution. The presentation looks at the differences and commonalities between the projects to identify directions and ideas regarding prediction of fish. Ceres uses a number of fish model from mechanistic multi-species models to single species statistical models, which allow for different focus (e.g. spatial domain, temporal coverage, distribution, recruitment), while C3S-MCF combines a multi-species fish model and remote sensing to detect front location.

Drivers of distribution of NEA mackerel in the Nordic Seas by means of Bayesian modelling and some attempts to spatially predict kelp biomass

Nikolaos Nikolioudakis

Northeast Atlantic (NEA) mackerel is a species of great economic and ecological importance, whose habitat expansion in the last decade has altered the biomass dynamics in the pelagic realm of the Nordic Seas. Mackerel is caught as west as Greenland and as North as Svalbard and this has caused concerns on the effects this expansion can have on other pelagic species, such as the Norwegian spring spawning herring, that compete for the same prey resources. Utilizing data obtained during the International Ecosystem Summer Survey in the Nordic Seas from the period 2011 to 2017, we used state-of-the-art modelling techniques, such as Bayesian hierarchical spatiotemporal models, to identify the factors affecting mackerel's distribution. Our findings showed that temperature in the upper 50m of the water column, food availability (approximated by mesozooplankton biomass), a proxy of herring abundance and longitude were the main factors influencing both the catch rates (proxy for fish density) and the occurrence of NEA mackerel. Stock size was not found to directly influence the distribution of the species; however, catch rates in higher latitudes during years of increased stock size were lower. Additionally, we highlight the improved performance of models with spatiotemporal covariance structures, thus providing a useful tool towards elucidating the complex ecological interactions of the pelagic ecosystem of the Nordic Seas. These results suggest that the distribution pattern of a pelagic fish species are far more complex than we imagine and not easily explained by our static picture of the ocean, as perceived from data derived standard scientific cruises. Indispensable as the latter may be, we need to improve our methods of capturing long term variability if we want to understand the complex ecological interactions in the pelagic ecosystems.

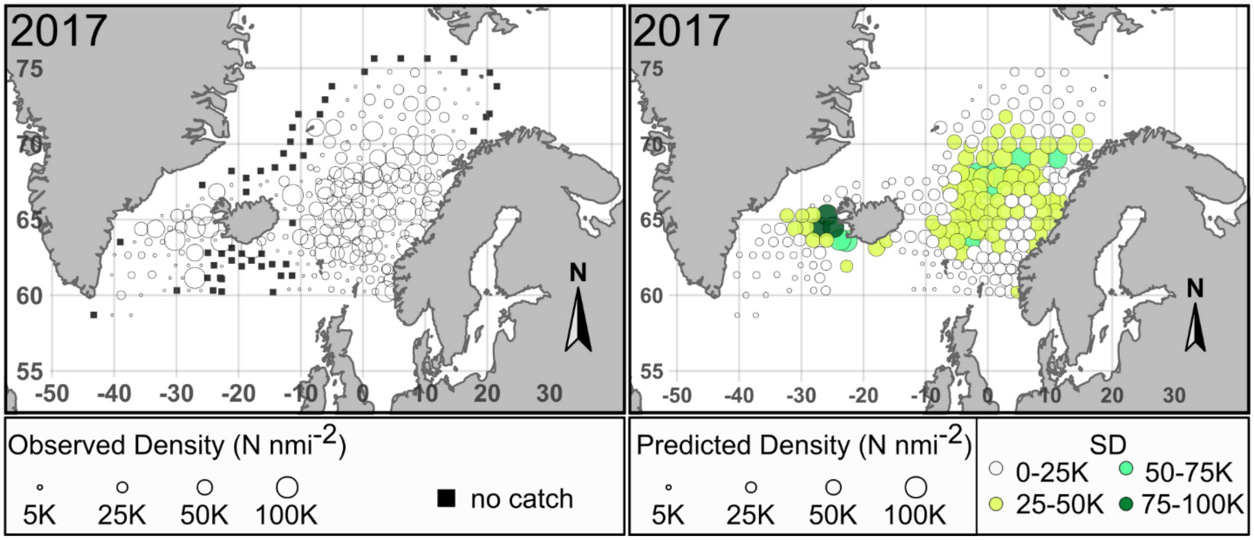

Figure 7. Observed mackerel densities (left panel) vs. predicted (mean posterior fitted) values for the positive density model (right panel) for 2017. Circle sizes in the right panel represent the estimated densities, whereas the colour scale indicates the uncertainty for each fitted value (K: thousands of fish).

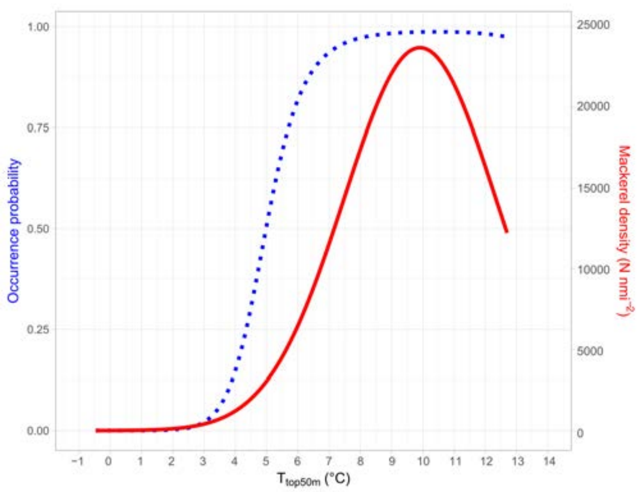

Figure 8. Model predictions for the probability of occurrence (blue dotted line) and the positive density of mackerel (red solid line), based on the assumption of a quadratic relationship with the mean temperature of the top 50 m.

Some attempts to spatially predict kelp biomass

Nikolaos Nikolioudakis

Work in progress regarding kelp biomass modelling was also presented to the group. Tweedie GAMs were selected to fit models of kelp biomass utilizing the Template Model Builder software. Depth and a combination of covariates representing bottom effects on kelps were found to provide the best fit, without the need for inclusion of a Gaussian latent field. Correlation of the model predictions against an independently collected kelp biomass dataset came out quite strong (r=0.83). These initial models are planned to be refined in order to identify means of improving them even more.

Shift in larval phenology of Nephrops norvegicus in the Irish Sea

Ryan McGeady, Dr Anne Marie Power and Dr Colm Lordan

The Norway lobster / Dublin Bay prawn (Nephrops norvegicus) is a valuable commercial species found in areas of muddy sediment on the seabed. Its distribution is discontinuous due to its dependence on suitable habitat and larval supply. The larval phase consists of 3 pelagic stages whereby development time is influenced by temperature and dispersal is governed by hydrography

Several historical plankton datasets for the Irish Sea were obtained from CEFAS. The datasets enabled the observation of an earlier shift in the timing of larval release in recent times (Figure 9).

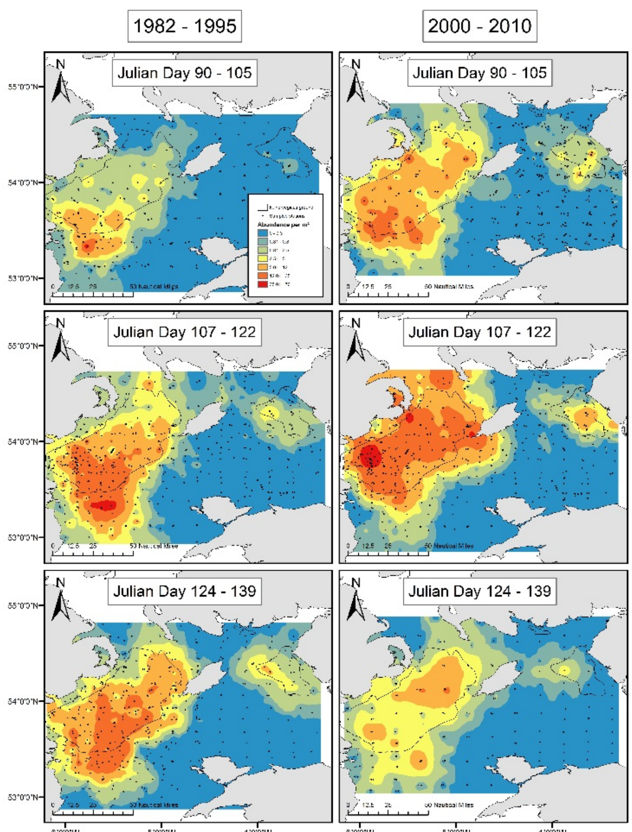

Figure 9. Comparison of spatio - temporal distribution of Stage I N. norvegicus larvae in the Irish Sea during the time-series 1982–1995 and 2000–2010 using IDW spatial interpolation.

The cause has been attributed to increasing water temperature on the sea bed during the embryo incubation period. Modelled bottom temperature data for the Western Irish Sea was extracted from the Atlantic – European North West Shelf - Ocean Physics Reanalysis from the Met Office (1985–2014). Warmer average temperatures during the embryo incubation period result in an earlier release of larvae. A 1°C increase in temperature led to a 22 day earlier first appearance of larvae ($r^2 = 0.97$, $P < 0.05$). The earlier shift in larval release may have significant implications for recruitment by way of trophic mismatch and current driven larval dispersal. Future work will focus on using particle tracking tools to examine the effect on retention of larvae.

Climate based multi-year predictions of Barents Sea cod stock

Anne Britt Sandø

Predicting fish stock variations on seasonal to decadal time scales is one of the major issues in fisheries science and management. Although the field of marine ecological predictions is still in its infancy, it is understood that a major source of multi-annual predictability resides in the ocean. Here we show the first highly skillful long- term predictions of the commercially valuable Barents Sea cod stock seven years in advance, by statistically exploiting predictability arising from the propagation of oceanic anomalies toward the Barents Sea and the strong co-variability between these hydrographic anomalies and the Barents Sea cod stock. Retrospective predictions for the period 1957–2017 capture well multi-annual to decadal variations incod stock biomass, with cross-validated explained variance of over 60%. For lead times longer than one year the statistical long-term predictions show more skill than operational short-term predictions used in fisheries management and lagged persistence forecasts. Our results thus demonstrate the potential for ecosystem-based fisheries management which could enable strategic planning on longer time scales. Future predictions show a gradual decline in the cod stock towards 2024.

Can we predict the demography and distribution of Northeast Atlantic mackerel with a mechanistic individual-based model?

Boyd, Robin, Roy, Shovonlal, Sibly, Richard M., Thorpe, Robert and Hyder, Kieran

Earth system models are able to project the physical state of the ocean with increasing skill. This has led to a first wave of ecological forecast products which capitalise on historical relationships between ocean physics and biology. However, it is possible that these relationships will break down under novel environmental conditions. One way to circumvent this problem is by developing mechanistic models that capture the underlying processes explicitly. We present a mechanistic individual-based model (IBM) of marine fish populations that incorporates spatial and temporal variation in food availability, temperature and exploitation. Key features of the IBM include: (1) realistic behavioural and physiological models; (2) representation of the full fish life cycle; (3) a spatially-explicit environment and (4) the incorporation of satellite remote-sensing data to represent the environmental drivers. Individuals are characterised by several state variables, including life stage, body mass, length, energy reserves and location. The behavioural and physiological models determine how the state variables of each individual change in response to their local food availability and temperature. We then summarise the characteristics of all the individuals to obtain population dynamics, structure and distribution. To demonstrate the use of the model, we have calibrated it for mackerel (Scomber scombrus) in the North East Atlantic. The calibrated model successfully matches historical data on mackerel population dynamics and structure. We are now using the model to test the possible population consequences of future environmental scenarios by forcing it with projections of plankton availability and temperature from earth system models.