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

12-16 June 2017

ICES Headquarters, Copenhagen, Denmark

International Council for the Exploration of the Sea

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Executive summary

The Working Group on Seasonal to Decadal Prediction of Marine Ecosystems (WGS2D), chaired by Mark R. Payne, Denmark, met for the first time at ICES Headquarters, Copenhagen, Denmark, 12–16 June 2017. The group aims to develop and operationalise forecasts of marine ecological properties (e.g. distribution, recruitment, phenology) that are of direct relevance to the advice and monitoring activities of ICES. It is envisaged that this will be done via the development and production of "forecast sheets" together with potential end-users of the information, where the forecasts of relevant variables, their caveats and guidance about their interpretation are documented.

The group produced its first example of a forecast product during this meeting. A generic template to be used in producing and communicating these predictions was first developed, based loosely on the model of ICES advice sheets. One example of a "forecast sheet" was then fully populated, for the spatial distribution of blue whiting spawning based on species distribution modelling: the spawning distribution is expected to maintain its current "compacted" distribution close to the European continental shelf edge in 2018. Work was started on a second forecast sheet for the recruitment of Baltic Sea sprat.

A review of methods to validate the skill of ecological forecasts is being prepared. Based on approaches taken in meteorology, this work will provide a valuable framework for which to both assess and communicate the reliability of the forecasts developed here. These lessons have already been incorporated into the blue whiting forecast sheet.

WGS2D took advantage of its venue to interact with the ICES secretariat, and particularly with those familiar with the advice generation process. A useful discussion helped guide identify the types of variables that would be most useful to predict: the distribution of species was identified as being of particular value.

WGS2D has also initiated activities with its sister groups in PICES (the Study Group on Climate and Ecosystem Prediction, SG-CEP) and CLIOTOP. A joint theme session on ecological prediction has been proposed to the Fourth International Symposium on the Effects of Climate Change on the World's Oceans to be held in Washington DC in June 2018.

The group's progress was unfortunately limited by weak attendance. A particularly critical issue is that the current membership is dominated by scientists from the physical oceanographic observation and modelling communities, while there are currently no members from the ICES advice or monitoring communities. WGS2D will therefore be making active contact to these working groups over the next year to identify relevant ecological variables that could be predicted and to bring potential end-users of these forecasts into the group. Expanding the size and breadth of this group will be vital to its future success.

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)

1

Chair(s)

Mark R. Payne, Denmark

Meeting venue

ICES HQ, Copenhagen, Denmark

Meeting dates

12–16 June 2017

2 Terms of Reference a) – z)

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 tools 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

- Establishment of the group and a plan for how to address the ToRs;
- Production of the first WGS2D forecast sheet, for the spatial distribution of blue whiting spawning;
- Draft of a second forecast sheet, on the recruitment of sprat in the Baltic;
- Outline of a review of methods to verify ecological forecasts;
- A joint theme session co-sponsored by ICES WGS2D, PICES SG-CEP and CLIOTOP has been proposed to the Fourth International Symposium on the Effects of Climate Change on the World's Oceans to be held in Washington DC in June 2018.

5 Progress report on ToRs and workplan

ToR a) Identify case studies

WGS2D held a discussion together with members of the ICES secretariat about the potential applications of forecasts of the physical environment within the context of ICES work, and how this work could be applied to both advice generation and monitoring activities. The secretariat was generally positive and supportive of the idea and had several concrete suggestions about where forecasts could be developed and applied e.g. distribution of widely-distributed species such as Mackerel and by-catch species such as Hake. Contacting relevant working groups directly and in person was viewed as a useful way to development and uptake of forecast products, but it was suggested that having relevant demonstration products in hand first would greatly facilitate this process. WGS2D will begin the process of contacting relevant groups and identifying case studies over the course of the next year.

ToR b) Review methods for assessing predictability

Preliminary work towards a review of methods for assessing the predictive skill of ecological forecasts was presented to the group. 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 should be close to completion for the next WGS2D meeting.

ToR c) Assess predictability of selected case studies

Not addressed in year 1. However, the draft forecast sheets produced by the group this year already incorporate skill assessment.

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

A template for a WGS2D "forecast sheet" was developed. 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. A full example of a forecast sheet based on this template was prepared (see Annex 4) for the spatial distribution of blue whiting spawning: work was started on a second for the recruitment of Baltic sprat. Furthermore, work was 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 was created within the ICES GitHub repository (https://github.com/ices-eg/wg_WGS2D) to both host the necessary code and allow for ready updating of forecast sheets: the first code is expected to be populated there within the coming year.

ToR e) Delivery of forecast products

Not addressed in year 1. However, the draft forecast sheets produced by the group this year together with the publication of the code on which they are based already represent an important step towards routine delivery of these forecast products.

ToR f) Joint activities with PICES SG-CEP

A joint theme session co-sponsored by ICES WGS2D, PICES SG-CEP and CLIOTOP has been proposed to the Fourth International Symposium on the Effects of Climate Change on the World's Oceans to be held in Washington DC in June 2018. See Annex 2 for the text of this proposal. The PICES study group on Climate and Ecosystem Predictability (SG-CEP) is still in the process of being established, and closer coordination is expected to take place between the two groups in the future.

6 Revisions to the work plan and justification

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

7 Next meetings

The date and venue for the next meeting has yet to be decided.

Potentially, the group would like to meet back-to-back with the Working Group on Recruitment Forecasting in a Variable Environment (WGRFE) to discuss collaborations between the groups (provided WGRFE continues for a new term).

The date and venue for the next meeting will be decided at a later stage in conjunction with participants in WGS2D and other potential collaboration partners.

Annex 1: List of participants

Name	Institute	Country	Email
Mark R. Payne (Chair)	DTU-Aqua	Denmark	mpay@aqua.dtu.dk
Brian R MacKenzie	DTU-Aqua	Denmark	brm@aqua.dtu.dk
Anna K. Miesner	Centre for Ocean Life DTU-Aqua	Denmark	amie@aqua.dtu.dk
Robinson Hordoir	Swedish Meteorological and Hydrological Institute	Sweden	robinson.hordoir@smhi.se

Annex 2: Theme session proposal

The following theme session proposal was submitted to the Fourth International Symposium on the Effects of Climate Change on the World's Oceans as a session co-sponsored by groups from CLIOTOP, ICES (WGS2D) and PICES (SG-CEP).

The role of seasonal to decadal ocean ecosystem predictions in a changing ocean

Co-Chairs: Mark R. Payne (ICES WGSD), Jason Hartog (CLIOTOP), Elliott Hazen (CLIOTOP), Mike Jacox (PISCES SG-CEP), Desiree Tommasi (PISCES SG-CEP)

Abstract: Research examining the future impacts of climate forcing in ocean ecosystems has historically been focused on the climate change time scale (50-100 years and longer). While such projections provide critical information towards pro-active management, they unfortunately do not match the tactical decision-making timescales of most individuals, businesses, sectors or governments (typically measured in months to years), hindering the development of climate-ready management strategies. Fortunately, modern ocean models are rapidly developing the ability to make skilful forecasts of the physical (and more recently the biogeochemical) components of the ocean system on finer spatial scales and at seasonal, annual and even decadal timescales. These physical/biogeochemical forecasts can potentially be used to drive forecasts of biological and ecosystem variables that are of direct relevance to end-users and can be used to inform strategies for coping with and adapting to climate change and variability. In this session, we welcome contributions across a broad range of topics relating to predicting climate impacts on ocean ecosystems, including 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) proposed or current uses of physical and/or biological forecasts within a climate-change adaptation context, including advice and management frameworks. Contributions that span a range of these topics are particularly encouraged. As the focus of this session is on prediction (i.e. the seasonal to decadal timescales) we dissuade contributions focused solely on projection (climatic timescales), except in cases where they can give insights into the challenge of predicting ocean ecosystem variables.

Proposed speakers:

- Carlo Buontempo, Manager of the Sectoral Information System of Copernicus Climate Change Service at ECMWF;
- Francisco Doblas Reyes, Barcelona Supercomputer Center;
- Lisa Goddard, Director of Columbia University's International Research Institute for Climate and Society;
- Daniela Jacob, Director of Climate Service Center Germany (GERICS);
- Claire Spillman/Oscar Alves (or representative from Bureau of Meteorology, Australia); Senior Research Scientist/Director, Earth Systems Modelling ;

- Samantha Siedlecki or Isaac Kaplan NOAA NWFSC/JISAO J-SCOPE (Seasonal Coastal Prediction of the Ecosystem).

Annex 3: Scientific Highlights

Forecasting the spawning distribution of blue whiting (*Micromesistius poutassou*)

Anna Miesner, DTU-Aqua, Denmark

The spawning distribution of blue whiting has been shown to vary substantially in time and space, potentially causing problems for both the monitoring and management of this species. Previous studies have shown that changes in the spatial distribution of spawning of blue whiting are associated with changes in the North Atlantic sub-polar gyre (Hátún *et al.*, 2009). The gyre is a large-scale oceanographic feature that plays a key role in the distribution of major water masses in the spawning region (Hátún *et al.*, 2005).

A recent study based on larval data obtained from the Continuous Plankton Recorder, with results supported across three independent data sets, has shown that the salinity regime during the time of spawning in blue whiting determines the extent of the spawning distribution of blue whiting (Miesner *et al.*, in prep.). Anomalously high salinity conditions generally cause an expansion of suitable spawning habitat, while the reverse causes a contraction (Miesner *et al.*, in prep.).

Seeing that the North Atlantic sub-polar gyre region stands out as one of the most predictable marine regions worldwide (Matei *et al.*, 2012; Meehl *et al.*, 2014), the switch from one salinity regime to the next can potentially be forecasted. The high predictive potential of the marine climate in the spawning region of blue whiting, coupled with the persistence of salinity at depth with skilful forecast lead-times up to 2-3 years, enables us to forecast the extent of blue whiting's spawning distribution at time scales relevant for the stock's management.

References

Hátún H, Payne MR, Jacobsen JA (2009) The North Atlantic subpolar gyre regulates the spawning distribution of blue whiting (*Micromesistius poutassou*). Canadian Journal of Fisheries and Aquatic Sciences 66: 759–770.

Hátún, H., Sandø, A. B., Drange, H., *et al.* (2005) Circulation Influence of the Atlantic Subpolar Gyre on the Thermohaline Circulation. Science (80-.). 309:1841–1844.

Miesner, A.K., MacKenzie, B.R. and Payne, M.R. (2017) Changes in the spawning distribution of a migratory fish (blue whiting, *Micromesistius poutassou*) in relation to the marine climate. In Preparation.

Methods for assessing and communicating forecast quality

Anna Miesner DTU-Aqua, Denmark

Allan Murphy, a pioneer in the field of forecast verification, wrote an essay with the title "What makes a forecast good?", where he distinguished three main aspects that contribute to a good forecast (Murphy, 1993), namely consistency, quality and value. A forecast is consistent, if it agrees with a forecaster's best judgement about the circumstances. If a forecast corresponds to what has actually happened, it has quality. And if the forecast is able to assist in the decision making process, benefit stakeholder or creates economic profit, it is valuable. When making biological forecasts, we aim to achieve all three aspects, however in terms of forecast verification, quality is our main focus.

The quality of a forecast can be described in terms of accuracy, skill and reliability, where accuracy describes the level of agreement between forecast and truth (represented by observations), skill refers to the accuracy of the forecast compared to a reference forecast and reliability is defined as the agreement between forecast (probabilities) and the observed frequencies of the event being forecasted (Murphy, 1993). The aim of this study is to provide tools that can easily be applied in assessing the quality biological forecast and are successful in clearly and efficiently communicating model skill.

No single verification measure captures all aspects of forecast quality, accordingly there is general consensus that a comprehensive assessment requires more than one verification metric (Jolliffe and Stephenson, 2012; Stow *et al.*, 2009). In the following, we will describe one numerical and two graphical tools that enable an efficient assessment and communication of forecast quality.

Skill scores are an easy way to summarize the skill of a forecast relative to a reference. There are many skill metrics one can use to compute skill scores, such as the root mean square error (RMSE) or the ranked probability score (for more skill & metrics see e.g. Jolliffe and Stephenson, 2012; Wilks, 2011). It is important to note, that the choice of the reference is crucial as it determines the relative skill of the forecast. The main references applied in atmospheric science are persistence and long-term climatology forecasts (Jolliffe and Stephenson 2012), while also another forecast/model or a sample climatology can serve as a reference.

A graphical way to summarize the relative forecast skill, is by means of a Taylor Diagram which shows the correlation coefficient, RMSE and standard deviation of different forecasts relative to a reference in one single plot (Taylor, 2001). Since it does not reveal information on the bias, it is advisable to state this information separately or to compare results when using an unbiased RMSE (Jolliff *et al.* 2009).

Another tool that is widely used in meteorology is the reliability diagram (Jolliffe and Stephenson 2012). It answers following question: Given the forecast of a certain event how well do the corresponding observations match? As such, it requires a fairly large dataset, since the sample needs to be partitioned into subsamples conditional on forecast probability. It is helpful to add the probability of climatology (of a certain event) and a line of "no skill", which is halfway between climatology and the diagonal of perfect reliability. Additionally, Weisheimer and Palmer (2014) came up with a colour scheme similar to a traffic light approach and verbal categories to aid understanding and interpretability when comparing different reliability diagrams and to summarize reliability spatially.

References

Jolliff, J.K., Kindle, J.C., Shulman, I., Penta, B., Friedrichs, M.A.M., Helber, R., and Arnone, R.A. 2009. Summary diagrams for coupled hydrodynamic-ecosystem model skill assessment. J. Mar. Syst. **76**(1–2): 64–82. Elsevier B.V. doi:10.1016/j.jmarsys.2008.05.014.

Jolliffe, I. T. and Stephenson, D. B. (2012) Forecast Verification: A Practitioner's Guide in Atmospheric Science. 2nd ed. I. T. Jolliffe and D. B. Stephenson, eds. West Sussex: Wiley-Blackwell.

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Weisheimer, A., and Palmer, T.N. 2014. On the reliability of seasonal climate forecasts. J. Rocal Soc. Interface 11(April): 20131162. doi:10.1098/rsif.2013.1162

Wilks, D. S. (2011) Statistical methods in the atmospheric sciences. 3rd ed. Academic Press.

Environmental Forcing of Sprat Recruitment in the Baltic Sea and Potential Applications to Forecasting

Brian R. MacKenzie, DTU-Aqua, Denmark

Understanding how climate change, exploitation and eutrophication will affect populations and ecosystems of the Baltic Sea can be facilitated with models which realistically combine these forcings into common frameworks. Here, we evaluate sensitivity of fish recruitment and population dynamics to past and future environmental forcings provided by three ocean-biogeochemical models of the Baltic Sea. Modelled temperature explained nearly as much variability in reproductive success of sprat (*Sprattus sprattus; Clupeidae*) as measured temperatures during 1973–2005, and both spawner biomass and temperature have influenced recruitment for at least 50 years. The three Baltic Sea models estimate relatively similar developments (increases) in biomass and fishery yield during 21st century climate change (ca. 28% range among models). However, this uncertainty is exceeded by the one associated with the fish population model, and by the source of global climate data used by regional models. Knowledge of processes and biases could reduce these uncertainties.

Published in Ambio 41:626–636 (2012)

Seasonal forecast of fish stock in Baltic & North Seas – Possibilities offered by Nemo-Nordic

Robinson Hordoir, SMHI, Sweden

Fish stock seasonal and inter-decadal forecast requires a forecast of the extension of water masses of precise temperature and salinity. The length of a mid-term forecast, with a time scale of months to a few years means that no data assimilation can correct the model biases during this time lapse. This means that during this time period, the model must rely on its natural skills to provide a realistic representation of the time evolution of the barotropic and baroclinic structure of the ocean. For large scale ocean areas, the structure of the ocean is the result of a long time scale evolution. In this case, having a right assimilated initial condition often allows a realistic representation at a seasonal time scale to the inertia of the model to change (persistence). On coastal shelves, the smaller size of the water mass makes that the persistence of the initial condition can be smaller. From an ocean modelling and forecast point of view, this means that the importance of the representation of ocean processes is set to even higher standards. We present Nemo-Nordic, a

Baltic & North Sea model that is both able to perform precise short term forecast, and provides a proper representation of the evolution of the thermo-haline structure in long term simulations (from 1 to more than 50 years). We believe this combination permits to set the model operationally to predict fish stocks in the Baltic and North Sea basins

Nemo-Nordic is the new operational model of SMHI (Swedish Meteorological and Hydrological Institute). The physical parameterisations implemented in the NEMO ocean engine permit a representation of the thermo-haline structure of the Baltic & North Sea on long term time scales due to a combination of several features that did not exist in previous forecasting models of the area. Nemo-Nordic provides a precise representation of the Baltic & North Sea surface height (SSH hereafter) which outperforms that of SMHI's former forecast ocean model HIROMB. For the North Sea basin, this feature allows Nemo-Nordic to provide a precise representation of the barotropic transports which dominate most of the Southern part of the basin. This in turns permits to allow to represent the cyclonic circulation of the North Sea and the right imports/exports of freshwater and heat. For the Baltic Sea, the representation of the sea level in both basins allows a good representation of the driving dynamics of the salt inflows. Such salt inflows are the drivers of the entire ecosystem for the Baltic Sea. Further, the model features in terms of mixing, parameterisation of the dense overflows, allow to represent long term baroclinic dynamics. This is especially true when it comes to the representation of fronts, haline or thermal stratification whether in Baltic or North Sea locations. In this brief report, we shall show the model results for some specific cases, which can provide a hint on its capabilities to provide "mid-term" forecast.

Annex 4: Example of forecast sheet

WGS2D Forecast Sheet 001-17-v0.1

Blue Whiting Spawning Habitat Forecast

Issued 14-06-2017. Valid through to 01-06-2018

Forecast

Oceanographic conditions have constrained the spawning distribution since 2013 (Figures 1, 2). A constrained distribution can be expected for the 2018 spawning period (Figures 1–3).

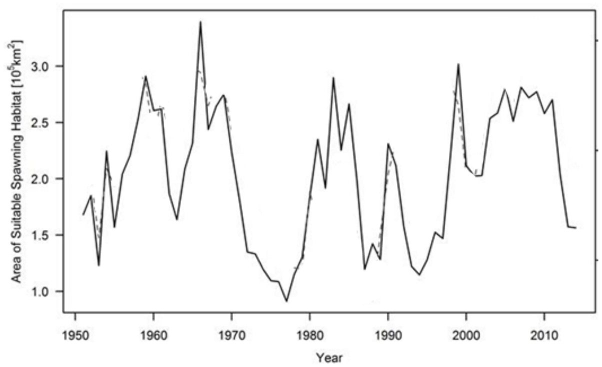

Figure 1. Time-series of the area (km²) of suitable spawning habitat of blue whiting in the month of peak larval presence (April).

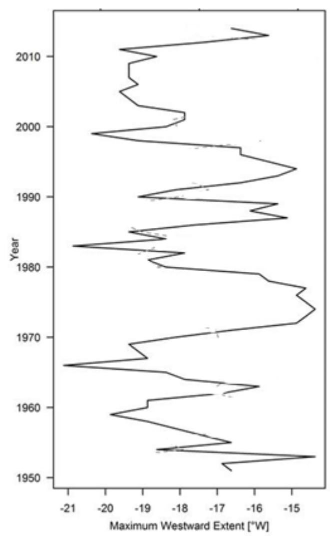

Figure 2. Time-series of the westward extent (longitude in degrees °W) of suitable spawning habitat of blue whiting in the month of peak larval presence (April).

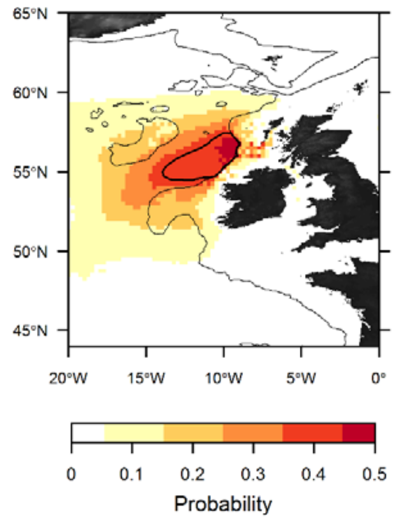

Figure 3. Projected spawning habitat for blue whiting in March 2018. The colour scale corresponds to the probability of observing blue whiting larvae in a single haul performed by the Continuous Plankton Recorder: probabilities > 0.4 (black contour line) can be considered as the core spawning habitat.

Background

The spawning distribution of blue whiting has varied in the past and has expanded, contracted and shifted locations (Figures 1, 2, 4). The dominant feature of these changes is a westward expansion away from the shelf-break region west of the northwest European continental shelf onto the Rockall plateau and Hatton bank region (Figure 4).

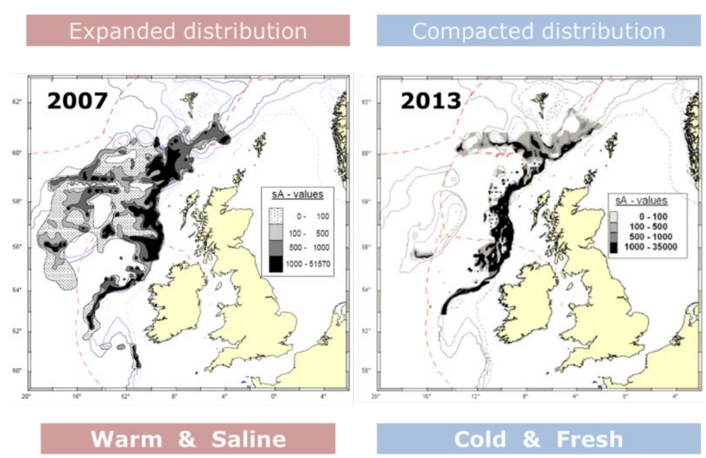

Figure 4. Spatial distributions of blue whiting from the International Blue Whiting Spawning Stock survey in two years characterized by different oceanographic conditions. Note the large difference in range occupied towards the west in 2007 compared to 2013.

A key ocean phenomenon which has been linked to these distributional changes is the sub-polar gyre (Hatun *et al.* 2009 CJFAS). The gyre is a dynamic large-scale ocean feature in the north Atlantic associated with the interaction of several major currents (Hatun *et al.* 2005, refs.) and plays a key role in the distribution of major water masses in the region. The spawning distribution of blue whiting has been linked to these oceanographic conditions, and in particular to the salinity in the region, occurring within a narrow salinity window (Figure 5).

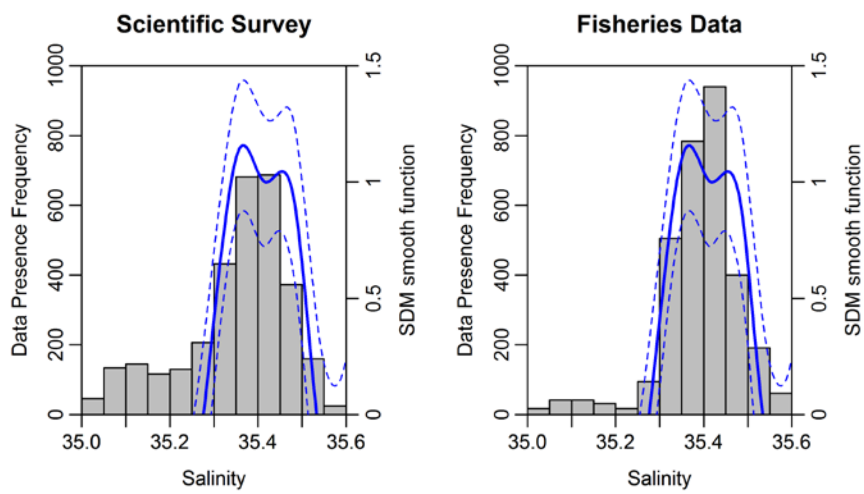

Figure 5. Presence frequency of spawning blue whiting (number of pixels with presences) observed in scientific surveys a) and caught in fisheries b) compared to the salinity (300–600 m) at which these observations were made (bars). The blue line indicates the modelled smooth function of blue whiting larval-presence obtained from the Species Distribution Model (SDM) based on larval blue whiting catches by the CPR survey d), with dashed lines indicating the standard error. Panel a) shows observations from late March/ early April, and Panel b) data shows data from March. The SDM was calibrated with CPR data from February to June.

The slow dynamics of oceanographic properties in the region can be used to provide reliable estimates of future distributions of water masses and thereby spawning habitat for blue whiting up to a year in advance.

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 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 given the high level of persistence in the ocean dynamics in the region.

Basis for Forecast

This forecast is based on a species distribution model developed by Miesner *et al*. 2017. 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 5). Core spawning habitat is defined as a probability (p) of observing larvae with $p \geq 0.4$ in a single haul from the CPR survey.

Forecasts of the physical environment (and specifically salinity at spawning depth) are derived by assuming that the most recent state of the environment (March 2017) will persist until at least the next spawning period (March 2018), and possibly beyond. The EN4 data set (v4.2.0) is used as the source of physical observations (Good *et al.* 2013).

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 significant for forecast lead-times up to 2–3 years (Figure 6).

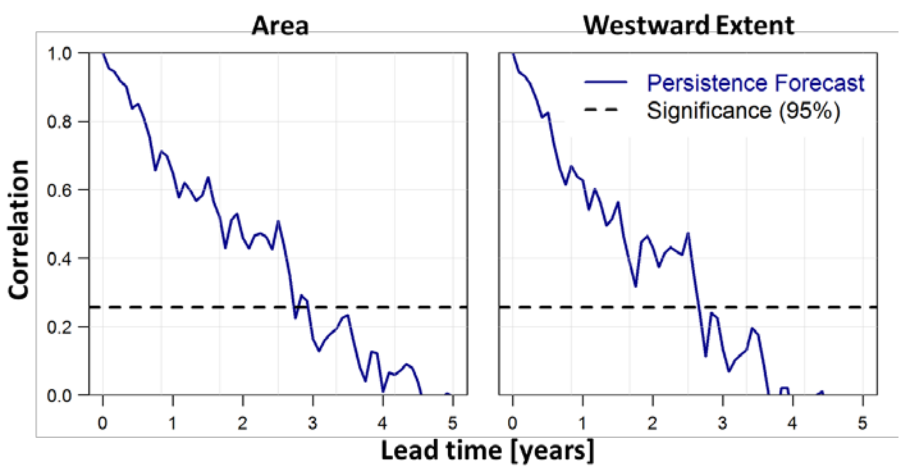

Figure 6. Skill assessment of forecasts of the area (km^2) and westward extent of potential spawning area for blue whiting in the waters west of the northwest European continental shelf. The plots show correlation based on persistence of ocean dynamics for various lead times into the future. The dashed line indicates the minimum significant correlation ($P > 0.05$).

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