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Towards a spatial integrated stock assessment model for European hake northern stock

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ABSTRACT

European hake (*Merluccius merluccius*) is a key species in the management of several mixed fisheries in the north-east Atlantic where regional spatial management plans are being set up. The wide spatial distribution of hake and the lack of knowledge of some processes involved in its spatial dynamics could hamper the assessment and management of hake.

To help understand the processes, we implemented a spatial version of the Stock Synthesis stock assessment model for northern hake, including available data on this stock and the associated fisheries. For the 1978–2012 time series, the model distinguished the Bay of Biscay, the Celtic Sea and a northern area aggregating the West of Scotland and the North Sea. The model considered an age-structured population for each age class and area, a seasonal migration, global recruitment allocated to areas and fishing fleets for each area. Parameters for stock and exploitation spatio-temporal dynamics were estimated by likelihood maximization for each quarter and area.

The comparison of spatial and non spatial models goodness of fit showed they were close, although the fit to abundance indices slightly improved with the spatial model.

Fishing mortalities, spawning stock biomasses and recruitments were slightly different from the current assessment model estimates, essentially at the beginning and the end of the time series. On average over the time series, fishing mortality estimates relative to the abundance were higher in the Bay of Biscay than elsewhere, spawning stock biomass estimates were higher in the Celtic Sea than elsewhere, and recruitment occurred mainly in the Bay of Biscay. Finally, the final spatial model estimated a strong movement from the northern area to the Celtic Sea. The final spatial model is a step towards a spatial assessment and management of the stock.

1. Introduction

European hake (*Merluccius merluccius*) is a demersal fish widely distributed over the north-east Atlantic shelf from Mauritania to Norway and in the Mediterranean Sea (Casey and Pereiro, 1995). It has been one of the most important commercial species in the north east Atlantic demersal fisheries since the first half of the twentieth century (Murua, 2010). European hake is assessed as three distinct stocks: northern, southern, both assessed by the International Council for the Exploration of the Sea (ICES), and Mediterranean. This study focused on the northern stock distributed from the northern Bay of Biscay to the Kattegat (ICES Division 3a, Sub-areas, 4, 6, 7, Divisions 8a, b, d, see Fig. 1).

Following concerns in the late 1990s about the low stock biomass and the possibility of recruitment failure, a range of measures were introduced (EC, 2001a, 2001b, 2002) in order to improve selectivity and protect juveniles, and a recovery plan was subsequently adopted (EC, 2004). These management measures, coupled with several years of high recruitment, lead to a stock recovery, with an increase of the spawning stock biomass (SSB) well above the precautionary approach level since 2009 (ICES, 2016). With the reformed Common Fishery Policy (EU, 2013), the European Commission is currently developing regional multi-annual management plans to address mixed fishery issues (STECF, 2015). Several framework directives, *e.g.* the Maritime Spatial Planning Directive (EU, 2014) and the Marine Strategy Framework Directive (EU, 2008), have provided the basis for the measures drawn up by the European Commission.

Hake is one of the main species included in the multiannual management plans for Southern and Northern European Western Waters (STECF, 2015) recommending a management at regional scale with target ranges of fishing mortality for individual species. As the hake stock is distributed over several management regions, it is of importance to consider the spatial distribution and dynamics of the stock and of the fleets exploiting it. This may improve the stock management, as it may allow to define management measures consistent with the

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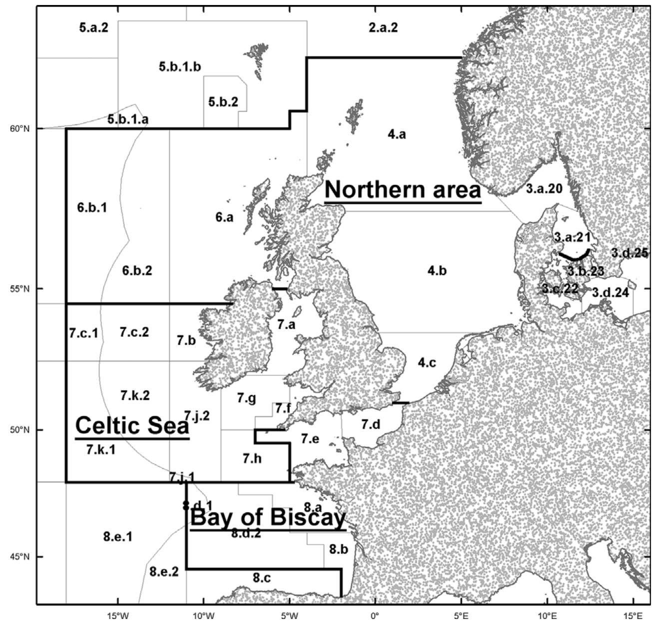

Fig. 1. Map of the areas modelled in the final spatial model. Areas are delineated by thick black lines, area names are in black, bold, underlined text.

spatial variations of the stock and fleet dynamics.

Since 2010 (ICES, 2010) the northern stock has been assessed using Stock Synthesis, version v3.24f (SS3) (Methot and Wetzel, 2013) based on length-structured data, avoiding the use of a potentially biased and uncertain age-length key (de Pontual et al., 2006). The current implementation of the SS3 assessment model for hake is, however, non spatial, ignoring the spatial variations of several biological processes and fishery related metrics, with spatially invariant selectivity patterns for some fleets, recruitment, and the absence of migrations. This may affect estimates of biomass and length structure (Cadrin and Secor, 2009; Cope and Punt, 2011; Gertseva and Cope, 2011), and hence stock management.

A spatial model can account for the spatial distribution of the fishing mortality associated with each fleet and thus reduce the potential bias in a non spatial model (Pelletier and Mahevas, 2005), improving estimates of biological processes parameters and biomass (Garrison et al., 2011; McGilliard et al., 2015). Furthermore, such models can potentially reveal additional information on stock dynamics and spatial variations in the impact of fishing, to improve the accuracy of management indicators and the evaluation of spatial management plans (Hampton and Fournier, 2001; Montenegro et al., 2009; Moustakas et al., 2006; Russo et al., 2014).

Currently, the background knowledge required for implementing spatially structured stock dynamics for hake is limited. Little is known about the annual variations in recruitment in the Bay of Biscay, the Celtic Sea and the northern nurseries. Hake is unevenly distributed over its range of distribution and its spatial patterns and habitat preferences are poorly understood. Mature hake migrate westwards from the shelf in autumn and winter and aggregate offshore for spawning (Poulard, 2001; Woillez et al., 2007). A northwards spawning migration, through the reproductive season, has been proposed by several authors (Alvarez et al., 2004; Guichet, 1996) and a migration from the Celtic shelf to the Bay of Biscay has also been proposed (Guichet, 1996), but neither of these migrations has yet been confirmed. Recently, migration between the West of Scotland and the North Sea has also been proposed (Baudron and Fernandes, 2015). All these migrations are difficult to estimate with the available models and data, and given the lack of appropriate tagging data (Bertignac et al., 2012; Drouineau et al., 2010).

Several spatial models have been proposed to account for the spatial features of hake northern stock and estimate uncertainties. Drouineau et al. (2010) proposed a spatial model fitted to a short time series to improve knowledge of hake growth and migrations. Bertignac et al. (2012) proposed a spatial Stock Synthesis model fitted to a long time series to provide information for the development of spatial management of hake, such as on the spatial distribution of hake. These preliminary studies provided new insights into the spatial stock dynamics of hake, such as estimates of spatial distribution, recruitment and fishing mortality, and migrations. They also highlighted several limitations of the models, such as confounding between model estimates (Bertignac et al., 2012), a failure to reproduce spatial patterns, such as mature hake aggregation on the Celtic Sea shelf, or a migration from the Bay of Biscay to the Celtic Sea (Drouineau et al., 2010). To improve their models, they suggested that further exploration was required on the assumptions about selectivity patterns, the definition of the migrations, the allocation of recruitment to each area and on alternative spatial structures. Furthermore, Drouineau et al. (2010) excluded the North Sea and the West of Scotland, and Bertignac et al. (2012) included them aggregated with the Celtic Sea. Yet, there have been recent changes in stock dynamics in the North Sea (Baudron and Fernandes, 2015) calling for a more precise modeling of this area. An improved model, addressing the issues described above, is required to improve knowledge of hake stock dynamics.

Spatially structured Stock Synthesis models have already been implemented for other species and fisheries: Day et al. (2015) assessed toothfish stocks in the Macquarie Island fishery, Kolody, 2010; Sharma, 2014 assessed an Indian Ocean Swordfish Fishery, Thorson and Wetzel (2015) assessed canary rockfish stocks off the US West Coast, Cass-Calay et al. (2015) assessed red snapper stocks in the Gulf of Mexico, all using a spatially structured Stock Synthesis model. Among others, they noticed the high sensitivity of their models to poorly-known processes, and that while developing a more complex model, one may replace problematic assumptions with other problematic assumptions. Hence the implementation of such models requires an accurate specification of the model, and, more specifically, an appropriate spatial structure and scale given the available knowledge, data and management needs. Finally, spatial assessment should be treated with caution as misspecified assumptions of spatial features and lack of data may lead to a poorly performing model (Maunder and Piner, 2017; Punt et al., 2015).

From the non spatial Stock Synthesis model currently used to assess the northern hake stock (ICES, 2016), we have implemented a spatial Stock Synthesis model, describing explicitly the Bay of Biscay, the Celtic Sea and a northern area including the West of Scotland and the North Sea. The population dynamics component of the model can, therefore, allow for spatial variations in the demographic structure, the recruitment and migration estimates. Selectivity patterns and fishing mortalities[1] for each commercial fleet and indices of abundance from scientific surveys are calculated for each area. This spatial Stock Synthesis model was fitted to spatially disaggregated catch and survey data. Statistical metrics of goodness of fit were used to evaluate its relevance for integrated assessment of the northern hake stock. Spatial and global estimates of biomass are then discussed to assess whether this spatial model provides new insights into the fishery. Finally we discussed lessons raised by the modeling process for implementing spatial models using currently available data and scientific knowledge.

2. Material and methods

2.1. Model description

2.1.1. Current non spatial Stock Synthesis assessment model

Stock Synthesis is a statistical framework for calibration of population dynamics model using a diversity of fishery and survey data

[1] Here fishing mortalities are relative to the abundance, see formulae in Appendix B in Supplementary material.