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Stock-based vs. fleet-based evaluation of the multi-annual management plan for the cod stocks in the Baltic Sea

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ABSTRACT

This study evaluated the EU 2008 multi-annual plan for Baltic cod stock recovery. The plan combines harvest control rules that set TACs with reductions in direct effort (*E*) and fishing mortality (*F*). Performance and robustness of the plan are tested with a management strategy evaluation model (MSE). Stochastic simulations are carried out under different scenarios of recruitment and sources of uncertainties. Under the different magnitudes of errors investigated, the plan in its current design is likely to reach precautionary targets for the Eastern and the Western Baltic cod stocks by 2015. It is, however, more sensitive to implementation errors (e.g. catch misreporting) than to observation errors (e.g. data collection) when the (i) current settings of the ICES single-stock assessment model are maintained, (ii) intended fishing effort reduction is fully complied with, and (iii) biological parameters are assumed constant. For the Eastern Baltic stock, additional sources of uncertainties from fishery adaptation to the plan are tested using a fleet-based and spatially explicit version of the model which leads to higher reductions in *F* and no significant change in management robustness. The relative difference between both approaches is mainly due to differences in exploitation patterns in catching the same amount of fish. The effort control is demonstrated to be more efficient when supplemented with a TAC and avoids un-intended effects from fishery responses, e.g. spatial effort reallocation. Medium term economic evaluation of fishery performance shows an initial reduction in profit with effort and TAC reductions, but profit is always positive.

1. Introduction

By the start of 2009, the Eastern Baltic cod (*Gadus morhua*) spawning stock biomass (SSB) was less than the precautionary limit (B_{lim}) and the fishing mortality (*F*) estimates were above the agreed target (ICES, 2008b, 2009a). Western Baltic cod SSB has fluctuated around B_{pa} in 2007–2009 but *F* in 2009 was estimated to be above the agreed target (ICES, 2008b, 2009a). Both stocks are harvested by several nations, and a multi-annual management plan by the EU Commission was agreed in 2007 (EU Commission, 2007) and implemented in 2008 with the purpose of rebuilding the stocks. The 2008 management plan (EU Commission, 2007) consists of an *F*-adaptive regulation system based on a gradual reduction of *F* by 10% per year for both stocks translated into a total reduction in TAC and effort of 10%, together with indirect effort regulation measures through area closures. The plan targets *F*s of 0.3 and 0.6 for the Eastern and the Western cod stocks, respectively. The decision rules are to be applied on a yearly basis using the most recent estimates of SSB and *F*, in order to determine the TAC for the following year. Hence, the perceived state of the stock dynamics determines the management actions and the decision making process and gives limited space for negotiations between stakeholders.

The purpose of this paper is to evaluate the expected outcome and performance of the 2008 management plan in achieving stock recovery for both stocks. The evaluation was developed in FLR (Kell et al., 2007; www.flr-object.org) using a management strategy evaluation (MSE) framework (Bastardie et al., 2010; EFIMAS, 2004–2008; www.efimas.org) for running stochastic simulations of stock and fisheries dynamics. The MSE tool is used for scenario evaluation of the relative performance of different management options and decisions for reaching the management objectives of sustainable exploitation of the cod resources. One key aspect is the testing of the robustness of the management options against various sources of uncertainty, such as errors in data collection and in the implementation of the plan, in order to get an indication of the sensitivity of the management option being tested. The MSE stochastic simulation framework comprises two elements (Rademeyer et al., 2007): the operating model (OM) and the management procedure (MP). The OM represents standard plausible alternative population states such as different spawning stock–recruitment (SSB–R) relationships, and their dynamics over time. The MP or management procedure is the combination of the available simulated data, the

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stock assessment ('perceived' stock status) and the management model or harvest control rule (HCR). Another important aspect of MSE is the feedback of management decisions from the HCR into the OM so their impact is reflected in the simulated stock dynamics.

In the first part of the present paper, the sources of uncertainties investigated in the management procedure are only stock-based, corresponding to the required minimum according to the ICES SGMAS (ICES, 2008b):

(i) The process error including random variation in recruitment success.
(ii) The observation error from data collection and data collation of CPUE indices for tuning fleets and the catch-at-age matrix used for the assessment.
(iii) The assessment or model error, which arises from the imperfect perception of the stock because of the use of a particular model.
(iv) The implementation or management error; e.g. from over-catching the TAC or discrepancies between the scientific advice and the managers' final decision (misreporting of catches from Eastern Baltic has repeatedly been pointed out as a main factor causing low stock size (ICES, 2008b, 2009a,b)).

The second part of the paper focuses on the fisheries. The Eastern and Western Baltic cod stocks were historically among the largest and commercially most important cod stocks in the North-East Atlantic, and are exploited by several nations including Denmark, Poland, Sweden, Germany, Latvia, Russia and Lithuania. The cod fishery is mainly a single species multi-fleet fishery, and mixed-fisheries issues are of minor importance as cod is the dominant species in the demersal fisheries. However, the fishing pattern, effort allocation, and fishing selectivity of Baltic cod are complex and vary considerably between gears, mesh sizes, countries, national fleets/fisheries, vessel size classes, seasons of year, and areas. The stocks are, consequently, exposed to spatial and seasonally targeted fishing behaviour. The main fishery is conducted with large-meshed demersal otterboard single-trawls and large-meshed cod gillnets. In more recent years, longline and hook fisheries have also become more frequent. The heterogeneity in fishing practices from different fleets and the technical management measures in force are often neglected aspects in MSEs, which tend to focus mainly on stock-based HCR management. However, local closures of spawning basins (EU Commission, 2007) and possible effects on the age-specific, space and time disaggregated fishing patterns may be of key importance for management success. Most of these aspects were investigated in a previous study (Bastardie et al., 2010) by developing a fleet-based bio-economic model accounting for the effect of heterogeneity in fishing practices, effort allocation between fleets and spatial effort application. This effort-explicit modelling is re-used here to test some assumptions about departures from the constant fishing pattern assumed in the stock-based evaluation. Thus, while the stock-based evaluation focuses on testing the observation, assessment and model errors, the goal of the fleet-based evaluation is to encompass the complexity of the cod fishery to test the impact of possible fleet adaptation (considered implementation errors) on management success. The first objective of the paper is thus to evaluate the proposed management plan with regards to alternative assumptions. The second objective of this paper is then to compare the outcomes of a simple stock-based operating model and the more complex fleet-based OM including aspects of spatial dynamics and fleet behaviour. Finally, the third objective is to evaluate the effect of the plan on fleet-based economic indicators as a natural output of the fleet-based evaluation.

2. Materials and methods

2.1. Simulation frame

The Baltic cod 2008 management plan includes a number of key actions:

- Set a TAC that will result in a 10% reduction in the fishing mortality rate in each year of application compared to the fishing mortality rate estimated for the previous year (EU Commission, 2007; Article 6.1.a).
- Where the fishing mortality rate for one of the cod stocks concerned has been estimated to be at least 10% higher than the minimum (or target) fishing mortality rate (i.e. 0.3 or 0.6 for Eastern and Western Baltic cod stock, respectively), the total number of active fishing days shall be reduced by 10% compared to the total number of allowed fishing days in the current year (EU Commission, 2007; Article 8.4).
- Where the fishing mortality rate for one of the cod stocks concerned has been estimated to be less than 10% higher than the minimum fishing mortality, the total number of active fishing days E shall be reduced by the actual (0–10%) percentage. (EU Commission, 2007; Article 8.5).
- The TAC values are constrained to remain within an interval of ±15% avoiding large annual fluctuations from 1 year to the next, except if F is larger than 0.6 (Eastern Baltic cod stock) or 1.0 (Western Baltic cod stock), in which case the TAC may be reduced by more than 15%.

Consequently, reductions in fishing mortality are implemented as effort reductions supplemented by TACs. The interpretation of the rules can be presented as follows:

$$
\begin{aligned}
&\bar{F}_y = \bar{F}_{y-1} \times \frac{E_y}{E_{y-1}} \\
&\bar{F}_{y+1} = \bar{F}_y \times 0.9 \quad \text{if} \quad \bar{F}_{y-1} \geq F_{\text{target}} \times 1.1 \\
&E_{y+1} = \begin{cases} E_y \times 0.9 & \text{if} \quad \bar{F}_{y-1} \geq F_{\text{target}} \times 1.1 \\ E_y \times \dfrac{F_{\text{target}}}{\bar{F}_{y-1}} & \text{if} \quad F_{\text{target}} < \bar{F}_{y-1} < F_{\text{target}} \times 1.1 \end{cases}
\end{aligned} \tag{1}
$$

where index y denotes the year of the assessment (also called the intermediate year), $y-1$ the year with the latest catches and indices available, and $y+1$ the year for which the TAC is set. E_y is set to 1 for the start year of the plan. F_{target} is 0.3 or 0.6 for Eastern and Western cod stocks, respectively, $\bar{F}_{y-1}$ the terminal average F over ages (4–7 or 3–6 for Eastern and Western cod stocks, respectively) assessed using XSA (Shepherd, 1999; Extended Survivor Analysis) or a novel assessment model called SAM (State-space stochastic Assessment Model; Nielsen and Berg, 2009) capable of providing confidence intervals around F and N estimates (ICES, 2008b).

In the evaluation, the effort reduction was implemented such that the F used for calculation of TAC in the coming year in the simulation was given by:

$$
\begin{aligned}
&\bar{F}_{y+1} = \bar{F}_{y-1} F_{\text{mult}} F_{\text{mult}} \\
&F_{\text{mult}} = \begin{cases} 0.9 & \text{if} \quad \bar{F}_{y-1} > F_{\text{target}} \times 1.1 \\ 1.1 & \text{if} \quad \bar{F}_{y-1} < F_{\text{target}} \times 0.9 \\ \dfrac{F_{\text{target}}}{\bar{F}_{y-1}} & \text{if} \quad F_{\text{target}} \times 0.9 < \bar{F}_{y-1} < F_{\text{target}} \times 1.1 \end{cases}
\end{aligned} \tag{2}
$$

The 2008 management plan does not include any explicit specification of an effort change in the case of an F below the targeted F (Eq. (1)), and then it is assumed than E is multiplied by 1.1 if the target is over-shoot. Possible non-compliance of effort reduction requirements (i.e. misreporting of fishing activity) during the