Evaluation of Management Strategies for the Mixed North Sea Roundfish Fisheries with the FLR Framework

Hamon, K. [1], C. Ulrich [1], A. Hoff [2], L. T. Kell [3].

[1] DTU-DIFRES, Technical University of Denmark, Danish Institute for Fisheries Research, Charlottenlund Castle, 2920 Charlottenlund, Denmark
[2] FOI, Rolighedsvej 25, 1958 Frederiksberg C, Denmark
[3] CEFAS, Lowestoft Laboratory, Pakefield Road, Lowestoft, Suffolk NR33 0HT, England, United Kingdom
Email: clu@difres.dk

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EXTENDED ABSTRACT

Most demersal stocks keep being overexploited despite the numerous management measures implemented. New approaches in methods for providing scientific advice to fisheries management include simulation-based MSE (Management Strategy Evaluation), aiming at identifying management strategies robust to various sources of uncertainties. MSE are simulation models including management scenarios and allowing for testing alternative plausible hypotheses about stocks and fleets dynamics.

FLR (Fisheries Library in R) is an open-source collection of tools providing a generic modelling framework for constructing such MSE. FLR has been developed under the statistical computing language "R" in EU-funded research projects, and provides various compatible packages which can be freely combined by the user, thus insuring complete flexibility.

In this paper, we present a MSE application to the case study of the North Sea roundfish fisheries developed with FLR. The focus is on mixed-fisheries issues and technical interactions between fleets, including assumptions on fleet behaviour. We show that single-stock management objectives for cod and haddock cannot be achieved simultaneously using stock-based annual TACs (Total Allowable Catch) because of conflicting incentives to the fleets. We show that opposite hypotheses of fishermen behaviour (stop fishing when cod quota is exhausted or fish until haddock quota is exhausted while discarding overquota catches of cod) lead to dramatic changes in the probability of reaching cod recovery in the short-term.. This emphasises the need for establishing robust and consistent management plans accounting for main sources of uncertainties and interactions.

1. INTRODUCTION

The current diagnoses on commercial fish stocks are rather pessimistic. Most demersal stocks keep being overexploited despite the numerous management measures implemented. Main reasons for failures include scientific uncertainty, gap between scientific advice and management decisions and imperfect implementation of management policies. Learning from that, European scientists are turning toward management strategies robust to these sources of uncertainties, along the MSE (Management Strategies Evaluation) lines initiated by the International Whaling Commission (IWC, 1993; De La Mare, 1998). MSE should build upon frameworks that allows test of plausible hypotheses about the dynamics of the stocks and fleets before implementation (Anon. 2007).

FLR (Fisheries Library for R, http://www.flr-project.org) is an open-source collection of tools for the development of bio-economic simulation models of fisheries and ecological systems (Kell et al. 2007). FLR has been developed as a number of packages under R which is a "language and environment for statistical computing and graphics" available as a Free Software under the GNU General Public License (R Development Core Team, 2006) (www.gnu.org/licenses/licenses.html#GPL). By using R, FLR improves the transparency of scientific work; de facto all source codes are available which make them easy to review. In addition, the use of predefined classes allows fixing some data formats which are flexible and generic enough to suit most kind of fisheries-related data and models.

The development of FLR is taking place across a large number of research projects funded by EU (European Union) with different purposes and case studies, contributing to make this toolbox flexible and generic. In particular, the North Sea roundfish fisheries were considered a good candidate for testing the flexibility and genericity of FLR with regards to the mixed-fisheries aspects. The North Sea roundfish fisheries are among the most complex of Europe. Numerous fleets from nine countries and using different gear types are sharing the fishing rights on several roundfish stocks, and the level of technical interactions is very high. Some stocks are historically low while some others have increased. Some management issues have been addressed for this case study:

- In this mixed species context, the single species management by TAC (Total Allowable Catches) looks inappropriate, as species are caught simultaneously.
- No socio-economic aspects are taken into account in the scientific advice.
- The emergency management measures such as cod recovery plan are complex and difficult to evaluate.
- The fisheries are strongly dependent on recruiting year classes leading to problems in assessment and forecast.

The high level of complexity makes the system very difficult to simulate, and a number of choices and simplifying hypotheses must be taken. This study focused mostly on the mixed fisheries aspect, including some economic and recruitment variability.

2. MATERIAL AND METHODS

2.1. The case study

The roundfish fisheries account for around 20% of the total North Sea landings value. The fisheries are distributed between human consumption fisheries and industrial fisheries. Human consumption fisheries use otter trawls, pair trawls, Nephrops-trawls, seines, gill nets or beam trawls. Roundfish can be caught as target species or as by-catch in flatfish specific and Nephrops specific fisheries (Hoff and Frost, 2006; ICES, 2007a).

Four main species compose the roundfish landings: cod, haddock, whiting and saithe. The distributions of these four species overlap to a large extent, with the result that they are usually taken simultaneously in mixed fisheries, although the fisheries for saithe is somehow more species-selective than the others.

2.2. Stocks

The study is limited to cod and haddock, which are the main target species and the ones with the highest level of interaction. Cod is currently severely overexploited, while the haddock biomass is at a high level. Biological data have been extracted from the International Council for the Exploration of the Sea (ICES, 2007a). The stock distributions can include some adjacent area (e.g. Skagerrak or Eastern Channel), like in the stock definitions considered by ICES working groups.

2.3. Fleets

The main focus is on the inclusion of both the fleet level (i.e. physical group of vessels) and the fishery/metier level (activity of a vessel from a fleet during one fishing trip). Currently available fleet data for catch and effort were provided by national labs to the Scientific, Technical and Economic Committee for Fisheries (STECF, 2007) working groups, covering most EU activities in the North Sea for 2003-2005. Belgium, Denmark, France, Germany, Netherlands, Scotland and United Kingdom were included initially.

Due to the high number of fleets landing the two species considered, some fleet aggregations were made based on, (i) availability of age-based data at the fleet level, (ii) relative importance of the fleet with regard to total effort and landings of cod and haddock and (iii) possibility of linkage with economic data. Eleven fleets have then been selected. Each fleet is defined as the combination of a country and a gear type. These fleets represent 85% of the effort of the countries covered, and 54% and 87% of the total landings for cod and haddock respectively. The remaining fleets have been gathered in an OTH (other) fleet in order to cover the total fishing mortality.

Each fleet can engage in several fisheries ("metiers") each year. Metiers are defined as gear type x mesh size category, following STECF specifications. 49 metiers are so defined, with 1 up to 9 different metiers defined for each fleet.

The unit of effort is kWdays. Catch at age data were provided for most metiers. When the sum of product (of landings numbers and mean weights) didn't match the total landings provided for the same metier, a simple scaling procedure was used. The difference between the catch at age so obtained and the total catch at age provided in ICES data was allocated to the "OTH" (others) fleet.

The economic cost and earnings data by fleet were drawn from the AER (Annual Economic Report) database collected from 2003 to 2005. The data are distributed on vessel type (main gear) and length. Economic parameters (e.g. price of capacity, price flexibility etc.) used in the models are estimated from historical economic time-series.

2.4. Methodology

1. FLR

The North Sea roundfish system has been simulated in R using various FLR packages and objects and also the common R classes (vector, matrix, dataframe, array…). A particular effort has been made to make the best use of the available packages, and the missing methods were coded in a consistent manner for further use in the generic framework.

The packages used were FLCore, containing the core classes and methods; FLAssess and FLXSA, containing the basic methods for assessment and the XSA function (extended survivor analysis; Darby and Flatman, 1994); FLOE, designed to simulate observed data by including uncertainties; FLEcon, containing some basic economic models.

2. Operating model (OM)

The simulated stocks were divided in two periods: the historical part, estimated from the 2007 ICES assessment working group (WG), and the recent past (2004-2005) and future, simulated using ICES WG data and parameters. Maturity and natural mortality are kept constant and equal to WG estimates.

Main equations are given in appendix A. In the simulated period, population is estimated using eq. (1) and (2). Projection of the mean weights at age in stock is modelled as random variables without trend. Expected value at age is the last value of the smoothed time series eq. (3). The WG estimates of recruitment are used up to 2004. The stock-recruitment relationship (SRR) was a segmented regression model, chosen on the basis of lowest AIC among a range of usual alternatives. Recruitment from 2005 onwards is predicted with the SRR function (eq. (4), including autocorrelation and lognormal error (eq. (5) to (9)).

Fishing mortality by fleet and metier is calculated from effort, catchability (eq. (10)) and selectivity (eq, (11)). Projections use the constant 2003-2005 average. Weights at age in landings and discards in projections are proportional to weights at age in stock, with proportion coefficients calculated from historical data. An effort multiplier is calculated every year based on the harvest control rules and a hypothesis on fishermen behaviour, and used to calculate the annual level of effort in projection (eq. (12)). The effort multiplier is either set at the maximum or minimum across the F (fishing mortality) multiplier by species corresponding to the TAC. No model of effort allocation is implemented, and the percentage of effort spent in each metier is thus kept constant.

Mortality rates, landings and discards by fleet are calculated with eq. (13) to (16).

Quota share for each stock and each fleet are calculated as landings share of the previous year, and the catches made by each fleet exceeding this quota share are considered as overquota, and thus not recorded in landings (black-landed or discarded)

The AHF economic model (Hoff and Frost, 2006) estimates the dynamic change (entry/exit) in fleet capacity given previous years profits, which are evaluated from standard economic indicators (landings revenues, variable and fixed costs) and exogenous price levels scaled according to supply. Large scale decommissioning plans are not considered in the model. The economic model of capacity is used as a process-based model for simulating the maximum effort a fleet segment can physically exert in a period, and thus acts as an upper bound for changes in effort from year to year.

3. Management procedure (MP)

The management procedure combines three main steps, **sampling** of data from OM, stock **assessment**, and management implementation with **harvest control rules** (HCR) to set management measures.

The abundance indices used to calibrate the stock assessment are simulated based on “true” stock numbers, including a random error in order to mimic observation errors in the data. The catch data used in assessment do not include the overquota catches.

The “perceived” stock corresponds to the assessment based on XSA with traditional settings used in ICES. This perceived stock is then projected forward as in the Short-Term Forecast method used by ICES, in order to define a TAC by stock two years later. The TAC is based on some complex HCR reflecting the most recent EU-Norway agreements and proposals of the EU Commission, i.e.:

- Short-term target is to keep or rebuild stock within safe biological limits of precautionary approach (SSB> Bpa and F<Fpa)

- Long-term target F is Fmsy (maximum sustainable yield)
- TAC should not vary by more than 15% up and down from year to year
- If SSB is assessed below Bpa, HCR should insure that it doesn't decrease furthermore. In the same way, if F is assessed above Fpa, it should not increase.

The usual precautionary approach reference points are taken from ICES and Fmsy (fishing mortality giving the maximum sustainable yield) from ACFM (Advisory Committee on Fishery Management) summary sheets (http://www.ices.dk/iceswork/ACFM.asp).

4. Scenarios

Two different scenarios are tested, the "Maximum" and the "Minimum" scenarios. In the Maximum scenario, the fleets are assumed to go on fishing until their last quota share is exhausted, thus fishing more than the quota defined for the limiting stock (in our case cod). In the Minimum scenario, the fleets are assumed to stop fishing when their first quota share is exhausted, thus not fishing up the whole quota for the non limiting stock. Both are considered with the same management procedure. 100 stochastic iterations are run for each case.

3. RESULTS

We present here only the simulation results at the stock level (SSB, recruitment, F and catches), no figure by fleet is presented, although simulations outputs are available. For each variable, the "true" value (OM) is plotted in black and the perceived estimate (MP) in green. Relevant reference points are drawn in red.

Regarding the objectives described in the HCR, it is clear that differences in assumed fleet behaviour gives opposite answers. Under the "Minimum" assumption (Figure 1), both stocks are within safe biological limits in 2010 with 50% probability, but at the conditions of constantly decreasing catches for both stocks (as the HCR is primarily driven by the need to rebuild cod SSB), and thus low revenues for the fleets. On the contrary under the Maximum scenario (Figure 2), the probability of having the cod stock back above Blim is lower than 25%, but the catches are maintained at a high level. Furthermore, in that scenario, the stock of haddock falls also below Bpa by the end of the simulation, when the TAC is driven by Fmsy in the HCR, indicating the Fmsy may not be a sustainable reference point and should probably be revised.

In spite of observation error in survey indices, the perceived stock is close from the simulated stock, indicating a quite robust assessment method. Indeed XSA is driven mostly by the catch at age matrix. However, in case of large overquota catches because of mismatch between single-species TAC (cod stock under the Maximum scenario), the perceived catch does not account for the overquota catches leading to major differences in the "true" and perceived catch-at-age matrices. The F resulting from stock assessment is therefore considerably lower than the "true" F, whereas the biomass estimate is more robust. This is due to the fact that the relative age distribution remains unchanged in our model, and then the fishing mortality only is scaled down.

4. DISCUSSION

These scenarios illustrate well the crucial issue of accounting for mixed-fisheries aspects for sustainable fisheries management. Single-species analysis of EU HCR (corresponding to cod trajectories in Figure 1 and haddock trajectories in Figure 2) may estimate reasonable chance for cod recovery and sustainability, but under alternative but plausible assumption of overquota catches the recovery is strongly jeopardised. This underlines the need to set single-species TAC at levels consistent with each other, as bycatch will always occur. This has long been acknowledged by the industry, but no progress has been made so far to implement it at the policy level. It is clear that in reality the level of effort may be intermediary between the minimum and maximum assumption, and some work is ongoing to introduce alternative assumptions based on single-fleet's own incentives (ICES, 2007b), but using two antagonist assumptions allow us to bound the range of plausible projections.

FLR has proven its high flexibility in this study; however its use led to a long and comprehensive coding of the MSE, as FLR provides some predefined objects and methods but most of the processes remain to be coded by the user. But in return, developing such MSE provide useful feedback for the further development of FLR, and most of the functions we coded ourselves will be included in future packages and then available for further use. Besides, numerous MSE examples are currently on the FLR website helping the creation of new simulation models. The computing time is still high due to the nature of the objects used and the large number of fleets included in our model, however this did not prevent using FLR for complex case studies. The perfect modelling language does not exist, and the FLR team favoured a flexible, user-friendly and open-source framework rather than high computing speed. Moreover, further development are made in that direction, and the release of a new FLR version specifically designed for stochastic simulation should speed up the computing in the future.

In this example, we have used the MSE for comparing TAC scenarios under alternative assumptions of fishermen behaviour. It could be easily adapted to evaluate alternative management scenarios, including part of the complex fishery-based days at sea limitations implemented in the North Sea under the cod recovery plan, as well as alternative hypotheses of fleet behaviour and effort allocation. Economic results by fleet can also be estimated. Such a MSE could thus be used in the future for designing long-term management plans robust to various sources of uncertainties and accounting for mixed-fisheries aspects.

5. AKNOWLEDGEMENTS

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APPENDIX A: EQUATIONS

Population dynamics

$$N_{a+1,y+1} = N_{a,y} \times \exp(Z_{a,y}) \quad (1)$$

$$N_{+gp,y+1} = N_{+gp-1,y} \times \exp(Z_{+gp-1,y}) + N_{+gp,y} \times \exp(Z_{+gp,y}) \quad (2)$$

Weight at age

$$Wt_{a,y} = w_a \times e^{\varepsilon} \quad \varepsilon \sim N(0, \varphi_a) \quad (3)$$

Stock-Recruitment relationship

Segmented regression

$$R = \begin{cases} SSB < \beta & : \alpha \cdot SSB \\ SSB \geq \beta & : \alpha \cdot \beta \end{cases} \quad (4)$$

Recruitment residuals

$$N_{r,y} = f(SSB_{y-r}) \exp(\varepsilon_y - \sigma^2 / 2) \quad (5)$$

$$\varepsilon_{y+1} = \gamma \varepsilon_y + \eta_{y+1} \quad (6)$$

$$\eta_y \sim N(0, \sigma_\eta^2) \quad (7)$$

$$\sigma^2 = \ln(CV^2 + 1) \quad (8)$$

$$\sigma_\eta^2 = (1 - \gamma^2)\sigma^2 \quad (9)$$

Fleet dynamics

Catchability

$$q_{fl,y} = \frac{\overline{F_{fl,y}}}{E_{fl,y}} \quad (10)$$

Selectivity

$$S_{type,a,fl,y} = \frac{F_{a,y} C_{type,a,fl,y}}{C_{a,y} \overline{F_{fl,y}}} \quad (11)$$

Effort

$$E_y = Emult \times E_{y-1} \quad (12)$$

Mortality rates

$$Z_{a,y} = M_{a,y} + F_{a,y} \quad (13)$$

$$F_{type,a,y} = \sum_{fl} q_{fl,y} S_{type,a,fl,y} E_{fl,y} \quad (14)$$

$$F_{a,y} = \sum_{type} F_{type,a,y} \quad (15)$$

Catch equation

$$C_{a,fl,y} = \frac{N_{a,y} F_{a,fl,y} (1 - \exp(-Z_{a,y}))}{Z_{a,y}} \quad (16)$$

Symbols used in equations

$N_{a,y}$	Numbers of fish by age and year
$Z_{a,y}$	Total mortality by age and year
$+gp$	Age of the plus group
$Wt_{a,y}$	Mean weights at age by year
w_a	Expected weight at age
φ_a	Variance of weight at age
SSB_y	Spawning stock biomass
α, β	Stock-recruitment model parameters
r	Age of recruitment
ε_y	Recruitment residual by year
σ^2	Variance of recruitment residuals
γ	Autocorrelation in recruitment residuals
η_y	Innovation in the recruitment residuals
σ_η^2	Variance of recruitment residual innovation
CV	Coefficient of variation of recruitment residuals
$q_{fl,y}$	Catchability by fleet and year
$E_{fl,y}$	Effort by fleet and year
$C_{type,a,fl,y}$	Catch by type (discards or landings), age, fleet and year
$S_{type,a,fl,y}$	Selectivity by type, age, fleet and year
$F_{type,a,y}$	Partial fishing mortality by type, age and year
$F_{a,y}$	Fishing mortality by age and year
$M_{a,y}$	Natural mortality by age and year

APPENDIX B: RESULT FIGURES

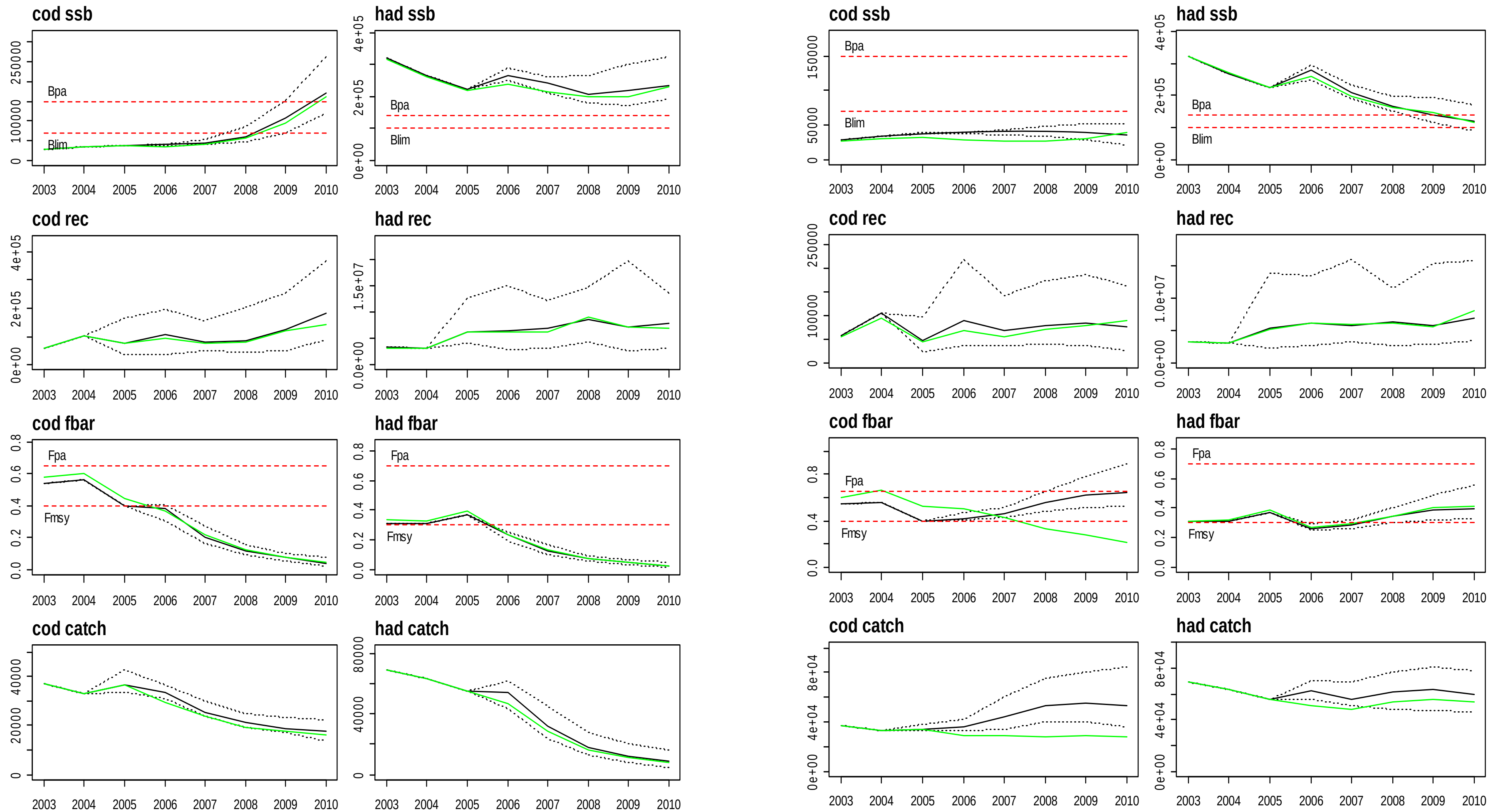

Figure 1 and 2. SSB, recruitment, Fbar and catches for cod (left) and haddock (right) over the period 2003-2010. Black lines represent the “truth”, and green the perceived system. Full lines correspond to the median values, and dotted to 25 and 75% quantiles. Figure 1. represents scenario Minimum and Figure 2. scenario Maximum.