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Comparison of stock management with production, difference, and age-structured models using operating models

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A R T I C L E I N F O

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Management strategy evaluation (MSE) was used to test the assessment and management performance of three assessment methods in combination with harvest control rules. The assessment procedures considered were: the eXtended Survivors Analysis (XSA), the Schaefer production model, and the difference model. Four HCRs were considered: first, fishing mortality was set on the basis of the relationship between the current biomass and a reference biomass; second, fishing mortality was gradually reduced (or increased) until it reached a required target; and the third and the fourth HCRs were similar to the first and second but with imposed TAC constraints. The stock that was generated in the operating model (OM) resembled the eastern Baltic cod stock. For the XSA assessment, two options were used: XSA with default shrinkage of terminal fishing mortality to the average of the estimates, and XSA with low shrinkage. The simulations showed that for stock assessment, the XSA models performed much better than the difference and Schaefer models. However, for the data tested, the difference and Schaefer models performed somewhat better in terms of management performance than the XSA models, especially the XSA model with default shrinkage.

1. Introduction

Fishery management usually requires estimates of historical stock sizes and predictions of future catches and stock size under various fishing mortality or fishing effort conditions. To make these estimations and predictions, scientific advisory bodies apply mathematical models that are typically age-structured and have different levels of complexity. ICES, the International Council for the Exploration of the Sea, is the main advisory body on fishery management for stocks exploited in most European waters. The standard ICES procedure for estimating biomass and fishing mortality for stocks in the northeast Atlantic involves the use of the eXtended Survivors Analysis (XSA; Shepherd, 1999) or Integrated Catch Analysis (ICA; Patterson, 1998). Surplus production models (e.g., Schaefer, 1954) are used less often for fish stock management but have been used within the ICES community for Greenland halibut and anglerfish (ICES, 2009), and have been used routinely by ICCAT (International Commission for the Conservation of Atlantic Tunas) for tuna and tuna-like species (ICCAT, 2010). Difference models were developed as an alternative to production models (Deriso, 1980; Horbowy, 1992) and may be useful for stocks in which recruitment undergoes larger variations because recruitment is modelled separately or taken as an external variable.

Age-structured models require historical age data from commercial catches and surveys, which are costly to obtain. In addition, for some species, there are problems with age determination (e.g., cod in the Baltic, ICES (2006a)). Thus, it would be interesting to compare the results of a stock management method that employs age-structured models with one that is based on simpler production or difference models that demand less data.

Recently, computer-intensive methods have been increasingly used in stock management studies, and a management strategy evaluations (MSEs) approach has been applied (e.g., Patterson et al., 2001; Kell et al., 1999, 2005; Dichmont et al., 2006; Rademeyer et al., 2007). The MSE typically consists of an operating model (OM), and a management procedure (MP) which includes an assessment method and a harvest control rule (HCR) (Kell et al., 2005; Dichmont et al., 2006; Rademeyer et al., 2007). The OM is assumed to represent "true" resource dynamics and is the basis for generating assessment and projection data. Next, the assessment model is fitted to the generated data, and finally, a projection of catch and biomass development is performed. Performance statistics are calculated, allowing for conclusions to be drawn on the usefulness of a given management method in light of the precautionary approach and fishery benefits. Other important processes, such as decision making and fishery adaptation, may also be included in the simulations. In most cases, MSEs have been used to test the

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performances of different management strategies using a given assessment method. Management procedures employing different assessment methods (e.g., age-structured models, production models or difference models) have rarely been contrasted. An example of such an application comes from Punt (1993), who compared the application of a surplus production model and an *ad hoc* tuned VPA (virtual population analysis) for the management of the Cape hake stock off the western coast of South Africa, and Dichmont et al. (2006) who tested three different assessment methods in management procedures for the Australia's Northern prawn fishery.

In the present study, the MSE approach was used to evaluate the performance of management procedures utilising three assessment methods and four HCRs. The assessment methods tested were: the XSA (Shepherd, 1999), the Schaefer production model (Schaefer, 1954), and the difference model (Horbowy, 1992). This report evaluates both the ability of the stock assessment methods to estimate biomass using historical data as well as the performance of these methods in achieving stock management objectives (e.g., high stable catches) when they are combined with harvest control rules. In terms of biological parameters, the stock generated for the OM resembled the eastern Baltic cod stock. Model performances were tested on generated stock that was similar to Baltic cod because of the limited progress in consistent age interpretation for cod, despite the fact that work on ageing consistency has been conducted since the early 1990s (ICES, 2006a). The inconsistency in ageing may affect stock assessment and prediction; thus, it is of value to test whether simpler assessment methods can perform satisfactorily in stock management.

2. Methods

The terms operating model (OM), management procedure (MP), harvest control rule (HCR), performance statistics, process error, and observation error are used as defined by Rademeyer et al. (2007).

2.1. Operating model

A model of a stock with specific dynamics was generated for a period of 20 years (e.g., 2005–2024) using two classical equations of stock dynamics: the exponential decay of cohort numbers and the Baranov catch equation (Appendix A.1). Stochasticity (process error) was introduced into the generated values by adding random lognormal error to the following values: initial stock numbers, recruitment depending on the spawning stock biomass (SSB), and fishing mortality (*F*). The generated stock resembled eastern Baltic cod stock ($M = 0.2$, maximum weight of approximately 10,000 g, begins maturing at age two, and most fish are mature at age four and older) and included the following characteristics:

- Initial stock numbers, weight-at-age in the catch and stock, and maturity and selectivity-at-age, as estimated in ICES (2006b).
- A hockey-stick sub-model for the expected value of recruitment that is dependent on the SSB (i.e., recruitment increases linearly with biomass to a specific spawning stock biomass level, and the next recruitment is constant).

In some simulations, the Ricker (1954) sub-model for recruitment dependence on biomass was used to test the robustness of the management procedures for different stock-recruitment relationships in the OM.

Fishing mortality (*F*) from 2005–2024 was assumed to be proportional to fishing effort (*f*), with catchability that was dependent on age but constant over time. The dynamics of fishing effort in the generated stock were determined according to the four scenarios presented in Fig. 1. These scenarios include *f* increasing or decreasing by 5% per year (scenarios 1 and 2), *f* increasing by 7% per year in first 10 years and then fluctuating (scenario 3), and *f* equivalent to *F* as estimated for Baltic cod from 1986 to 2005 (ICES, 2006b), scaled to 75% of the average *F* (scenario 4). These fishing effort options were selected to resemble the typical patterns of *f* in different fisheries. In options 1–3, the fishing effort value for first year was equivalent to an *F* of 0.4.

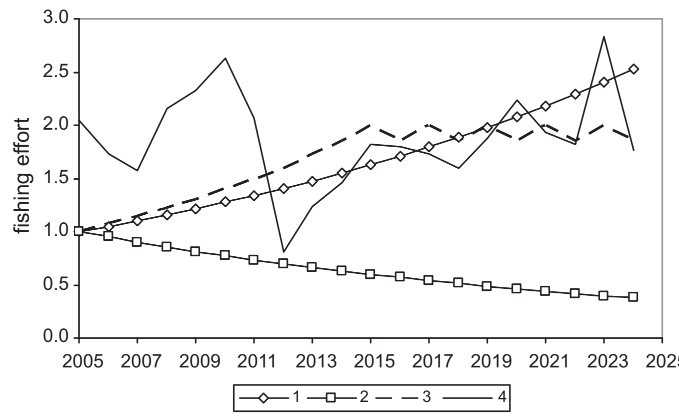

Fig. 1. The four fishing effort options considered in the "true" stock in the OM for 2005–2024.

2.2. Management procedure

The typical ICES procedure for stock assessment and advice on catch quotas was simulated. In this procedure an assessment performed in year *y* uses the assessment data for years up to $y - 1$, so that the stock estimates for the beginning of year *y* can be obtained. Then, an assumption for the catch in year *y* is made (e.g., equal to the total allowable catch (TAC) set for that year), and the stock at the beginning of year $y + 1$ can be projected. Next, catches for year $y + 1$and stock size at the beginning of year $y + 2$ are projected using given HCR and other selected options for fishing mortality.

Thus, to simulate ICES procedure, the data for stock assessment (total catch, catch-at-age in numbers, fishing effort, survey indices of stock size-at-age, including recruitment and mean weight in the stock) were drawn from the "true" stock (i.e., from the OM), and the assessment model was fitted. These assessment data were assumed to be distributed log-normally, with averages equal to those from the "true" stock and with a specified sampling variance (observation error). Two options for sampling variance were assumed, representing low and high levels of data collection error (Table 1).

After fitting the stock assessment model to the generated data, projections of stock size and catches were performed using specific harvest control rules, and the projected catches were assumed to be the catch (TAC) for the following year. These catches were then applied to the "true" stock. The assessment data from the projected (realized) catches and the "true" stock sizes were drawn, and new assessments and projections were performed. This sequence of consecutive assessments and projections was repeated for the next seven simulated years, i.e., 2025–2031 (Fig. 2). The time span of simulations was constrained to seven years, as the management plans are usually re-evaluated after a few years. The weight-at-age, maturity, and natural mortality were kept constant in the OM for 2025–2031 and equal to the averages of the values used for 2005–2024. Sampling from generated data, assessing and reassessing the stock, and projecting the catches were usually performed with 200 replications. Simulations were conducted in R using some elements of FLR including the FLXSA package (Kell et al., 2007; http://flr-project.org/).