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A fish stock assessment model using survey data when estimates of catch are unreliable

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ABSTRACT

Methods of assessment that depend upon commercial catch data can be undermined by misreporting or where parts of the catch, such as discards, are not accounted for. An age-structured model that makes use of survey data alone, and avoids this problem, is developed within a Bayesian framework so that routine stock summary statistics such as fishing mortality, recruitment and spawning stock biomass can be estimated with associated levels of uncertainty. It is also possible to estimate catch on a relative scale which can be compared to reported catches. The model is applied to West of Scotland haddock (*Melanogrammus aeglefinus*), a stock with suspected high catch misreporting. Stock trends derived from the model are consistent with conventional assessments that use catch data during periods of low misreporting. Estimated proportions of fish at each age in the catch correspond closely with observed values. Model estimates of total catches suggest substantial misreporting in some years, though the precision of the estimates is very low. Revised estimates of natural mortality are obtained from the model that are higher than conventional values used for this stock. These new values are generally consistent with those obtained from multispecies predation modelling for the adjacent North Sea stock. The model provides many of the basic quantities used for management advice. It should not be regarded as a replacement for more comprehensive analyses, but an additional tool to explore available data when catch information is unreliable.

1. Introduction

The aspiration of many stock assessments is to be able to estimate, on an absolute scale, the number of fish at each age in the stock and the associated fishing mortality. From these quantities it is possible to calculate spawning stock biomass and recruitment, and possibly infer a stock–recruitment relationship from which the full dynamics of the stock can be modelled. Such assessments frequently use age composition data from the landed catch which forms the core of the analysis. Some early assessment methods relied entirely on catch at age data, for example, virtual population analysis (VPA) (Gulland, 1965; Pope and Shepherd, 1982) and require *ad hoc* assumptions about initial values to perform the calculations. It is recognised that auxiliary information in the form of indices of abundance, greatly improve assessments by avoiding the need to make arbitrary assumptions about initial values (Doubleday, 1981; Deriso et al., 1985; Gavaris, 1988; Methot, 1990; Shepherd, 1999). These methods quickly became standard approaches to assessment and now form the everyday tools of fishery scientists. In many respects it is the auxiliary information – fishery independent data – which is essential and may be sufficient to perform an adequate assessment even when catch data are absent.

The ubiquitous use of catch at age data arises partly because it is often relatively inexpensive to collect and sampling can be done more easily on land, but also because it is the main source of information that scales any abundance estimate to an absolute value. However, not all of the catch is landed (FAO, 1994) so often only part of the catch is sampled. Furthermore, where catch controls are used to manage a fishery, the recorded catch is often distorted by actions to circumvent the regulations. As a result, not only may the scaling be distorted but variable bias in recorded catches may undermine the veracity of any assessment. In the European Union jurisdiction, many assessments have been abandoned because recorded catches are regarded as unreliable (ICES, 2010) leaving managers with little evidence upon which decisions can be based. Methods of assessment that can provide evidence of stock status to managers that are not dependent on catch data are therefore required.

Where abundance indices are available, for example from research vessel surveys, a possible solution to this difficulty is to assess fishing mortality and stock trends on a relative scale (Cook, 1997) without the use of catch data. Assessments using survey data

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only may not perform as well as those that include catch at age data (Patterson, 1998; Hammond and Trenkel, 2005) but where the catch data are compromised, these approaches may offer a useful alternative. In many assessments carried out by the International Council for the Exploration of the Sea (ICES) a survey-only method, SURBA, (Needle, 2002; Beare et al., 2005) is used. One particular difficulty of these models is that selectivity, natural mortality, and survey catchability parameters may be confounded and a conventional least squares fit of the model requires assumptions about one or more of these in order to obtain a unique solution. In practice, there is often some information on all of these quantities, although it may not be very precise, which could be used to aid fitting the model and hence estimate fishing mortality and relative catch. Using a Bayesian approach where informative prior information can be utilised offers a means of developing these models both to estimate quantities of interest and also to obtain appropriate estimates of uncertainty. In this paper a model is developed for the analysis of one or more surveys using prior information on fleet selectivity and natural mortality to estimate stock trends, relative catch and fishing mortality. The model is applied to a stock, haddock (*Melanogrammus aeglefinus*) in ICES Division VIa, where misreported catch is believed to be substantial and compared to the ICES assessment which is the recognised international consensus on the status of the stock. The ICES assessment attracts criticism because of the perceived unreliability of the reported catches. Results from the model developed here, which does not use these data, suggest the estimates of the quantities of interest could form the basis for fishery management advice and hence avoid the problems associated with biased catch data (ICES, 2010).

2. Assessment model

We assume at least one survey is available that provides an age structured index of abundance. In principle, even if the index is on a relative scale, measures of cohort abundance in successive time intervals will provide information on the total mortality experienced by the population. The task is to parameterise the mortality and the cohort signal in a way which accounts for sampling efficiency and measurement errors in the data so that the underlying abundance of the stock and its associated mortality rates can be estimated.

2.1. Structural model

The population, N, is assumed to decay with a total mortality Z according to the conventional exponential equation:

$$N_{a+1,y+1} = N_{a,y}\mathrm{e}^{-Z_{a,y}}$$

where a is an index for age and y is an index for year.

The total mortality is partitioned between fishing mortality F and natural mortality M so that:

$$Z_{a,y} = F_{a,y} + M_{a,y}$$

The total catch in number, C, of all fish taken by the fishery is assumed to follow the Baranov catch equation:

$$C_{a,y} = \frac{F_{a,y}N_{a,y}(1-\mathrm{e}^{-Z_{a,y}})}{Z_{a,y}}$$

In common with many fishery models we assume that the fishing mortality can be expressed as the product of an age effect or selectivity, s, and a year effect, f. Selectivity is the proportion of fish at each age entering the gear that are retained, while the year effect is a measure of the overall fishing mortality at fully selected age groups (i.e. when $s = 1$). Denoting commercial fishery selectivity by s^* the annual fishing mortality at age is given by:

$$F_{a,y} = s^*_{a,y}f_y$$

The change in fishing mortality rate from year to year is likely to be fishery specific and will depend on how it is managed. In general it might be expected that inertia in commercial fleets will mean that annual changes in F will be limited. It is assumed here that the year effect follows a simple time series model with a multiplicative random effect, ε:

$$f_y = f_{y-1}\mathrm{e}^{\varepsilon_y}$$

and

$$\varepsilon_y \sim \mathrm{Normal}(0, \sigma^*), \quad y \neq 1$$

where σ^* is the standard deviation of an irregular fluctuation associated with the commercial fleet. In effect it assumes that the time series of log differences in f is a stationary white noise process. Large values σ^* mean that the fishing mortality can exhibit large annual fluctuations.

While abundance indices may contain information on the annual change in mortality, they will not contain sufficient information to estimate selectivity at age freely because there is no data related directly to the catch. Hence, it is probably better to model selectivity with a relatively stiff function with few parameters for which informative priors can be specified. For trawl fisheries a common assumption, adopted here, is to use a standard two-parameter logistic selection curve where the proportion retained in the gear is a function of length. For ease of interpretation the selectivity function is parameterised in the form of the 50% retention length, L_{50} and selection range, sr. Hence for the commercial fishery, selectivity is taken to be dependent on mean length at age, $\bar{l}$:

$$\mathrm{logit}\left(s^*_{a,y}\right) = \left(\frac{\ln(9)}{sr^*}\right)\bar{l}_{a,y} - \frac{L_{50}(\ln(9)}{sr^*}$$

The other component of total mortality is natural mortality, M. It is unusual to find data that can be incorporated into a stock assessment in order to estimate natural mortality within the model. Lee et al. (2011) argue, based on simulation studies, that M can be estimated from stock assessment data provided the model is specified correctly. Where only survey data are used, it is unlikely that it is possible to estimate M since there are no observations on catch to partition total mortality. It is preferable to assume some knowledge of M in order to be able to estimate F. Natural mortality has been the subject of a number of reviews (Pauly, 1980; Vetter, 1988; Lorenzen, 1996, 2000) and empirical methods have been suggested for its estimation (Hoenig, 1983; Myers and Doyle, 1983). In the model described here, results of a meta-analysis of worldwide fish stocks by Lorenzen (1996) are used for their simplicity where natural mortality is related to weight. In particular it is assumed that M is a function of mean weight at age, $\bar{w}$:

$$M_{a,y} = \alpha(\bar{w}_{a,y})^{\beta}$$

where α and β are constants that mediate the change of M with age.

2.2. Observation equations

The indices of abundance, U, from surveys will be related to the true population in some way. This relationship may not be linear (Gudmundsson, 2004). However, a non-linear relationship increases the number of parameters and the degrees of freedom, and with noisy data are unlikely to be adequately estimated. For parsimony, it is assumed U is directly proportional to population size, where the proportionality constant is the product of an age