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Limits to the reliability of size-based fishing status estimation for data-poor stocks

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ABSTRACT

For stocks which are considered "data-poor" no knowledge exist about growth, mortality or recruitment. The only available information is from catches. Here we examine the ability to assess the level of exploitation of a data-poor stock based only on information of the size of individuals in catches. The model is a formulation of the classic Beverton–Holt theory in terms of size where stock parameters describing growth, natural mortality, recruitment, etc. are determined from life-history invariants. A simulation study was used to compare the reliability of assessments performed under different information availability scenarios, from data-limited, where none of the parameters are known beforehand, to different degrees of information availability cases where one or more parameters are known. If no parameters are known it is possible to correctly assess whether the fishing mortality is below F_{msy} in more than 60% of the cases, and almost always correctly assess whether a stock is subject to overfishing. Adding information about age, i.e., assuming that growth rate and asymptotic size are known, does not improve the estimation. Only knowledge of the ratio between mortality and growth led to a considerable improvement in the assessment. Overall, the simulation study demonstrates that it may be possible to classify a data-poor stock as undergoing over- or under-fishing, while the exact status, i.e., how much the fishing mortality is above or below F_{msy}, can only be assessed with a substantial uncertainty. Limitations of the approach are discussed.

1. Introduction

Exploited fish stocks are assessed with statistical models to determine the fishing mortality and stock biomass indices. The exploitation status of the stock is determined by comparing the assessed fishing mortality with reference points, i.e., whether the fishing mortality is above or below a particular reference point like the F_{msy}. For well-developed industrial fisheries such assessments are performed with sophisticated statistical models (Methot and Wetzel, 2013; Nielsen and Berg, 2014) relying on information from time-series of catches and surveys and, most often, on aging samples from catches and surveys. When such data are available, fishing mortality and biomass indices can be estimated with some confidence and the status of the stock relative to relevant reference points can be assessed. In many cases, however, such information is not available, and the stock is termed "data-poor". In particular the information of age is problematic because of the cost and uncertainty of aging procedures (Campana, 2001).

There is an increasing focus on developing formal methods to assess data-poor stocks (Punt et al., 2013). We define as "data-poor" the stocks where only current catch information is available (ICES, 2012, Categories 5 and 6), i.e. no time series, survey indices, information on age, or knowledge of vital rates are available. Such situations are common in developing fisheries, in mixed fisheries of highly diverse fish communities, or for by-catch species in well-developed industrial fisheries (Andrew et al., 2007; Costello et al., 2012; ICES, 2012). It is evident that the quality of assessments of data-poor species will not reach the level of data-rich fisheries (Bentley, 2014), therefore in such situations any qualitative information is welcome; just an indication of whether the fishing mortality is above or below a particular reference point will be informative. Our aim is to examine, through simulation, the accuracy level of a novel data-poor stock assessment method that has minimal data requirements, i.e., catch-at-size data and no time-series. The simulation and estimation models are the same in an effort to discover the reliability limits of this new data-poor stock assessment method under the best possible circumstances.

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Application to real data-poor stocks will therefore always be associated with a larger uncertainty.

In a data-poor stock, direct information of the size distribution of individuals in the catches is easily collected. Furthermore, indirect information about life-history parameters is available from data-rich stocks. The direct information about size makes it natural to base the model for stock assessment on size as the structuring parameter. Moreover, size is an important determinant of most vital rates of individuals (Brown et al., 2004); vulnerability to predation and food availability are related to individual size (Peterson and Wroblewski, 1984; Andersen and Beyer, 2006), and fisheries selectivity is often governed by size. Size-based projection and assessment methods have been developed for fish (Wetherall et al., 1987; Fournier et al., 1998; Maunder and Watters, 2003) and other marine species (see review in Punt et al. (2013), Chen et al. (2005)). In addition to the direct information from size in the catches, an assessment model needs information about life-history parameters related to growth, mortality and recruitment. A recent approach is the "Robin Hood" approach (Punt et al., 2011b; Le Quesne and Jennings, 2012; Hordyk et al., 2014a) which uses information from related stocks, from other stocks of the same species in a different area, or from other species in the same area, or relies on life-history invariants. The combination of information on size from the catch and life-history parameters from other stocks lays a solid foundation for a framework to assess the exploitation status of data-poor stocks.

Recently a formal framework based on individual size and life-history invariants was developed (Andersen and Beyer, 2013). The framework is an extreme version of the Robin Hood approach as only one parameter is needed to characterize the life-history parameters describing growth, mortality and recruitment: the asymptotic size. The framework goes beyond existing yield-per-recruit approaches to size-based assessment (Wetherall et al., 1987; Hordyk et al., 2014b; Kell et al., 2013) by including recruitment in the framework. Because recruitment is included, the framework makes it possible to simultaneously estimate the fishing mortality (F) and the biological reference point F_{msy}. Furthermore, the framework uses a size-based instead of a constant natural mortality. Since the framework is part of the growing family of data-poor assessments methods based on the Robin Hood approach, the results about the accuracy of assessments can be expected to have some generality.

A particular focus is to examine the importance of information on growth, i.e., size-at-age, on the assessment, and also whether it is possible to reduce the uncertainty associated with not knowing growth. Knowledge of growth enters directly into an estimation of fishing mortality. Imagine for example two fished stocks, where one is a fast growing species fished with a high fishing mortality while the other is a slow growing species fished with a low fishing mortality. In such a situation the size distribution of the catches of the two stocks will be very similar, and an assessment model is unable to assess that the two stocks are experiencing different fishing mortalities, without having information about the growth rate. To circumvent this issue we will examine whether it is possible to directly estimate the status of the stock, i.e., the ratio of the fishing mortality to a relevant reference point like F_{msy}. Since both the estimated fishing mortality and F_{msy} depend on growth rate in the same way, we hypothesise that when the ratio of the two is formed, the dependency of the assessment on growth cancels out.

The assessment of a data-poor stock can be boiled down to the simple question: is the stock undergoing overfishing (fishing mortality rate above some reference point) and is it overfished (spawning stock biomass below some reference point)? Our goal is to answer the part of the question dealing with the fishing mortality with yes or no and thereby support decisions to reach the desired target reference point. Here we deal only with assessing the fishing mortality and not the biomass. A minimal requirement for a data-poor assessment method to be useful is that it is able to correctly classify a stock more than 50% of the time; if not, a random classification would be more reliable (Carruthers et al., 2012). We investigate two aspects of classification success rate: firstly, the accuracy of the estimated fishing mortality and secondly the accuracy of the estimated stock status, i.e., the ratio between the fishing mortality and the reference point.

Our approach is to conduct simulations which mimic a data-poor situation. First, we use the framework of Andersen and Beyer (2013) to model the steady state size spectrum of an exploited stock; here, underlying life history parameters describing the stock are drawn randomly. Next, we simulate the size composition of catches. Finally, we imitate a data-poor assessment where some model parameters are set at default values, using the Robin Hood principle, while others are assumed known and thus set at the actual value for the particular stock. We focus on the ability of the assessment method to correctly classify the stock as undergoing overfishing or not, and in particular the improvement provided by aging (i.e., knowing the growth rate), and by knowing the physiological mortality (i.e., the ratio between natural mortality and growth rate).

2. Methods

The observations available to the assessment model consist of catches (numbers) of fish as a function of size. The aim of the assessment is to estimate the asymptotic weight (W_∞), fishing mortality (F) and selectivity (ψ_F) on the basis of those catches. This requires a model which can predict catches ($c(w|\theta, W_\infty, F, \psi_F)$) as a function of size (w), asymptotic weight (W_∞), fishing mortality (F), selectivity (ψ_F), and a set (θ) of species specific parameters. θ is the set of life-history parameters characterizing growth, mortality and recruitment. The model used here is in steady-state. In the following we introduce the model, explain the simulation of catches from a random stock, the estimation procedure, and finally the estimation of the stock status.

2.1. Theoretical model

The model used here follows the size-based theory of exploited fish stocks (Andersen and Beyer, 2013). The theory is based on individual size and uses a species independent set of life-history invariants θ, which together with the asymptotic size W_∞ define the stock. Growth is described by a von Bertalanffy-type of growth equation and natural mortality is size-dependent. Recruitment is described by a Beverton–Holt stock-recruitment function and the theory provides a prediction of the parameter that determines the steepness of the recruitment function. Based on this it is possible to calculate the size distribution of the stock and the recruitment. With a prescription of fishing mortality as a function of size it is furthermore possible to calculate the catch and fisheries reference points.

The size-based model is described briefly here; see Andersen and Beyer (2013) for a detailed description of assumptions and the derivation of population level quantities. The model equations are gathered in Table 1 and parameters and other notation in Table 2.

Growth rate and investment in reproduction emerges from a bioenergetic budget of an individual. The available energy for an individual follows a power law of its size with allometric exponent n (Eq. (1)) and growth constant A. The energy is allocated to activity (Eq. (2)) and, after maturation, to reproduction (Eq. (3)). The proportion of mature individuals is described by a function $\psi_m(w)$ changing smoothly from zero to one around the 50% maturation size η_m (Eq. (4)). The remaining energy is used for somatic