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An evaluation of an iterative harvest strategy for data-poor fisheries using the length-based spawning potential ratio assessment methodology

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ABSTRACT

Data on the length structure of exploited stocks are one of the easiest sources of information to obtain for data-poor fisheries, and have the potential to provide cost-effective solutions to the management of data-poor fisheries. However, incorporating the results from stock assessments into a formal harvest strategy, defined here as a harvest management system that incorporates monitoring, assessment, and decisions rules for a specific fishery, usually requires information on the total catch or catch-per-unit effort, data that are not available for many data-poor fisheries. This paper describes and tests a harvest strategy where only length composition data of the catch and knowledge of basic biological parameters are available. The harvest strategy uses a recently developed methodology for stock assessment that estimates the spawning potential ratio (SPR) for an exploited stock from the length structure of the catch (the length-based SPR model; LB-SPR), and uses an effort-based harvest control rule to iteratively drive fishing pressure towards a target level of SPR (40%). A management strategy evaluation framework was used to explore the behaviour of various parameterizations of the harvest control rule for three species with a diverse range of life-histories and M/k ratios ranging from 0.36 (unfished population dominated by large fish) to the Beverton–Holt invariant M/k of 1.5 (unfished population dominated by smaller fish). For all three species the harvest strategy was able to guide the fisheries towards the target SPR, although the time taken for the SPR to stabilise at the target SPR was greatest for the species with the greatest longevity and the lowest M/k. The results of this proof-of-concept study demonstrate that the combination of the LB-SPR assessment model with an iterative, effort-based harvest control rule can successfully rebuild an overfished stock back to sustainable levels or fish down a stock to the target SPR without significantly overshooting the target.

1. Introduction

During its development, fisheries science has tended to focus on large-scale stocks and industrial-scale fisheries, and fisheries management often relies on technically challenging mathematical and statistical models to estimate the current stock status and the exploitation rates of a fishery (Hilborn and Walters, 1992). These models often include hundreds of estimated parameters, require substantial amounts of data, are based on numerous assumptions, require considerable technical expertise to develop and run, and are often poorly understood by policy makers and other stakeholders (Cotter et al., 2004; Hilborn, 2003). In the last 15 years, the need to develop simple data-driven harvest policies that are understood by all stakeholders has received increasing recognition (Cotter et al., 2004; Hilborn, 2012, 2003; Kelly et al., 2006; Prince et al., 2011).

In addition to the issues arising from the complex nature of modern assessment models, the collection and analysis of the extensive data required for these models can be prohibitively expensive (Berkes et al., 2001). Many fisheries are small-scale and data-poor, and lack the data and the funds required for conventional assessment techniques (Berkes et al., 2001; Mahon, 1997; Stanford et al., 2013). Furthermore, the necessary resources for full quantitative stock assessments of many low value fisheries and stocks are often not available. In recent years, research on developing assessment techniques for data-poor fisheries has increased, and a suite of tools is evolving for scientists and managers to assess and manage stocks with limited data (Kelly et al., 2006; Klaer et al., 2012; MacCall, 2009; Wayte and Klaer, 2010). However, many of these

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methods still require considerable amounts of data from the fishery or regarding the biology of the target species, including a time-series of historical catch, catch-per-unit-effort (CPUE) trends, or information on the age structure of the stock, all of which are difficult to obtain for many data-poor fisheries.

Hordyk et al. (2014a) linked the expected size composition of a stock under equilibrium conditions and various levels of exploitation to two ratios: the ratio of fishing mortality to natural mortality (F/M), and the ratio of natural mortality to the von Bertalanffy growth parameter (M/k). They demonstrated that, in the unfished state, the proportion of large fish in a stock is determined by the M/k ratio. For example, the unfished length structure of stocks with very low M/k (e.g., 0.3) is dominated by large individuals distributed around the asymptotic size (L_∞), while unfished stocks with high M/k (e.g., 3.0) are dominated by smaller fish and relatively few larger individuals, with few fish attaining the asymptotic size. Hordyk et al. (2014b) extended these ideas to develop a model to estimate the spawning potential ratio (SPR) from the length structure of the catch, referred to as the length-based SPR (LB-SPR) model.

In general, the SPR is defined as the ratio of the total reproductive production at equilibrium for a given level of fishing mortality divided by the reproductive production in the unfished state (Goodyear, 1993; Mace and Sissenwine, 1993; Walters and Martell, 2004). This metric is usually referred to as *static* or *equilibrium* SPR (Slipke et al., 2002), and represents the expected equilibrium SPR if a stock was held indefinitely at the given fishing mortality and recruitment was constant. It is a direct function of instantaneous fishing mortality (F), the selectivity of the fishery, and the maturity schedule for the species. The equilibrium SPR is the most commonly used form of SPR, and is often routinely estimated in stock assessment software (e.g., Stock Synthesis; Methot and Wetzel, 2013).

Another, less common, use of the term SPR is the *transitional* SPR, which refers to the current *per capita* reproductive output compared to that in the unfished state (Parkes, 2001). While static SPR is proportional to fishing mortality, the transitional SPR reflects the history of fishing pressure over the life-time of each of a population's component cohorts, and thus represents a moving average of the fishing mortality rates (Parkes, 2001; Slipke, 2010). At equilibrium, the static and transitional SPR are identical, but when the fishery is undergoing change, they will diverge. For example, if a stock was at equilibrium and overfished, the static and transitional SPR would both be the same. If managers decided to close the fishery, or significantly reduce catches to almost zero, F approaches 0 and the static SPR approaches 1 instantaneously, because if no catch is taken for an indefinite period, the stock will rebuild back to the unfished equilibrium condition. In reality, however, a number of years are required for the previously fished year classes to grow through the stock and be replaced by unfished cohorts so that the actual reproductive potential of the stock, as measured by the transitional SPR, recovers more slowly. Compared to the static SPR, the estimate of the transitional SPR may be a more useful metric as it provides an estimate of the current stock status rather than the expected equilibrium status of the stock. Like other length-based methods that estimate SPR, or its proxies on the basis of size composition (e.g., Ault et al., 2005; O'Farrell and Botsford, 2006, 2005), the LB-SPR method is expected to estimate transitional SPR better than the static SPR. This must be kept in mind whenever comparing the estimates of one of these methods to the output of models such as Stock Synthesis, which present the static SPR (Methot and Wetzel, 2013).

The LB-SPR model estimates the SPR by comparing the observed length structure to the expected unfished length composition and has the advantage of requiring only minimal data: i.e., a representative length sample of the stock and estimates of the life history parameters: the M/k ratio, the asymptotic length (L_∞), a measure of the variability in length-at-age ($CV_{L\infty}$), and estimates of the size at maturity (Hordyk et al., 2014a,b). Information on the length structure of an exploited stock is often one of the cheapest and easiest data sets to collect (Quinn and Deriso, 1999). Furthermore, the biological parameters required for the LB-SPR method (Hordyk et al., 2014a,b) can either be obtained with relatively simple biological studies, or "borrowed" from other similar species by meta-analysis (Prince et al., 2014). Because the LB-SPR model has few data requirements and is relatively simple to understand and apply, the method has potential as a valuable tool for the assessment and management of data-poor fisheries. For example, the technique has been enthusiastically received by the fishing community in the Pacific island nation of Palau. Local studies to determine the size-at-maturity parameters for tropical reef species identified a high proportion of immature fish in the catch, and very few individuals that were actually mature, resulting in legislated management changes to increase the size at capture and rebuild the SPR (Prince et al., 2015). In this study, simulation modelling was used to provide a proof-of-concept that the LB-SPR assessment method can be used in harvest control rules to iteratively adjust fishing effort levels so that stocks achieve a target SPR.

The use of harvest strategies, or management plans and procedures, that contain biological reference points and robust decision rules are becoming increasingly common in fisheries management around the world (Punt, 2006). Three essential elements of a formal harvest strategy include: a monitoring and data collection programme, an assessment routine, and one or more decision rules, which are also known as harvest control rules (Smith et al., 2008, 2014). Harvest strategies provide a transparent mechanism for scientifically linking changes in management to the estimated status of the stock (Punt, 2006; Smith et al., 2008, 2014). Harvest control rules (HCRs) are essential for quota-managed fisheries, and typically HCRs are used to determine the annual total allowable catch (TAC) or recommended biological catch (RBC) by comparing the estimate of the current biomass (B) or fishing mortality (F) with a reference point (e.g., B_{MSY} or F_{MSY}) (Smith et al., 2008). However, these harvest strategies are often data-intensive, and typically rely on the output of age-structured assessment models, conditioned on a time-series of catch data, together with an estimate of the current biomass, to provide a recommendation for the adjustment to the TAC. Furthermore, the calculation of biomass-based reference points requires detailed information on the biology of the species, including knowledge of the underlying stock–recruitment relationship, which can be difficult to estimate (Hilborn and Walters, 1992; Myers, 2001).

An alternative approach is to use a harvest strategy which does not have a pre-defined biomass-based reference point, but rather uses an iterative harvest control rule to incrementally adjust fishing mortality until the stock stabilises at a target level; analogous to the "*find which direction to go in and take a small step that way*" approach advocated by Graham (1956, as cited in Holt (2009)). For example, Prince et al. (2011) describe an approach which uses information on catch rate and size composition to iteratively adjust the level of catch until size indices stabilised at the target levels. Likewise, Klaer et al. (2012) describe a method which estimates the current exploitation rate from the mean length in the catch, and adjusts the annual quota according to the ratio of the estimated and target exploitation rates. However, both these methods require estimates of total catch, the natural mortality rate, and CPUE trends, which are difficult to obtain in many data-poor fisheries.

This study uses a management strategy evaluation (MSE) framework to develop and explore a harvest strategy that uses a harvest control rule and the LB-SPR assessment method to iteratively adjust fishing effort until the stock stabilises at the target level for SPR. It demonstrates that without estimates of catch and effort, biomass or the current exploitation rate, an incremental harvest strategy