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Evaluating methods for setting catch limits in data-limited fisheries☆

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ABSTRACT

The majority of global fish stocks lack adequate data to evaluate stock status using conventional stock assessment methods. This poses a challenge for the sustainable management of these stocks. Recent requirements to set scientifically based catch limits in several countries, and growing consumer demand for sustainably managed fish have spurred an emerging field of methods for estimating overfishing thresholds and setting catch limits for stocks with limited data. Using a management strategy evaluation framework we quantified the performance of a number of data-limited methods. For most life-histories, we found that methods that made use of only historical catches often performed worse than maintaining current fishing levels. Only those methods that dynamically accounted for changes in abundance and/or depletion performed well at low stock sizes. Stock assessments that make use of historical catch and effort data did not necessarily out-perform simpler data-limited methods that made use of fewer data. There is a high value of additional information regarding stock depletion, historical fishing effort and current abundance when only catch data are available. We discuss the implications of our results for other data-limited methods and identify future research priorities.

1. Introduction

The majority of global fish stocks lack adequate catch, survey, and other biological data to calculate current abundance and productivity using conventional stock assessment methods. In developed countries, the fraction of fish stocks that are assessed ranges between 10 and 50%. This fraction is generally lower in developing countries where it ranges between 5 and 20% (Costello et al., 2012). This poses a significant challenge for the sustainable management of these stocks. Recent requirements to set scientifically based catch limits in countries such as Australia, New Zealand, and the United States, along with growing consumer demand for sustainably managed fish, have spurred an emerging field of methods for estimating overfishing thresholds and setting catch limits for stocks with limited data.

In 2006, the U.S. Magnuson-Stevens Fishery Conservation and Management Act was amended to require annual catch limits (ACLs) to prevent overfishing for most federally managed fish stocks, including many data-limited stocks. According to the National Marine Fisheries Service's (NMFS's) National Standard 1 Guidelines (2009), setting ACLs is a three-step process that begins by identifying an overfishing limit (OFL). The OFL is the annual catch when fishing the stock's current abundance at the maximum sustainable fishing mortality rate (F_{MSY}). In the second step, a harvest control rule is used to determine the acceptable biological catch (ABC). The ABC is a catch level equal to or less than the OFL that accounts for the scientific uncertainty in the estimate of the OFL. Finally, fisheries managers use the ABC to establish an ACL. The ACL is set to a level equal to or below the ABC and accounts for various ecological, social and economic factors in addition to uncertainty in management controls.

The most established basis for estimating an OFL is by a conventional stock assessment, which typically uses fishery time series data to estimate current stock size and productivity. However, many populations have insufficient fishery catch data, survey data, or information about life-history characteristics to support a conventional stock assessment, requiring the use of alternative, data-limited methods. Most data-limited methods are designed to operate on a single time series of annual catches (generally no fishing effort or survey data are available) with additional

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user-specified inputs for fisheries characteristics, demographic parameters, exploitation rate and/or stock status. Many of these methods are now being used in management, although they have not been thoroughly tested. Management strategy evaluation (MSE) is an appropriate tool to evaluate and compare the performance of existing methods across various types of fish stocks and relative population levels (see Section 2.2 for a detailed description of MSE). We use MSE in this research to test the performance of data-limited methods for various stock types and depletion levels (depletion is defined here as current biomass divided by unfished biomass).

It may be possible to make reasonable qualitative statements about the performance of various data-limited methods without undertaking an MSE. However detailed simulation evaluation enables the relative performance of methods to be quantified to support strategic decisions regarding data collection and selection of methods. Previous simulation evaluations of data-limited OFL-setting methods and ABC control rules have been conducted by Wetzel and Punt (2011) and Wilberg et al. (2011). Wetzel and Punt (2011) evaluated the performance of two methods (DB-SRA and DCAC) over a range of population and fishery dynamics. Limitations of their approach include the simulation of a relatively narrow range of fishery dynamics without simultaneously considering a realistic level of uncertainty and bias in all of the inputs to the methods under examination (e.g., natural mortality rate, *M*). Wilberg et al. (2011) simulation tested a more comprehensive range of data-limited methods. However, not all data-limited methods were applied to all stock types preventing a complete performance comparison (Vaughan et al., 2012). Their approach was also criticized on the basis of a relatively narrow range of simulated life-histories and discrete simulation of error and bias. We aim to address these criticisms by (1) simulating a wide range of fishery and population dynamics and (2) assigning probability distributions for bias and imprecision to more of the inputs to data-limited methods (e.g., depletion, *M*). Such an approach may better reveal the trade-offs among management objectives and provide a more detailed account of the performance characteristics of data-limited methods.

2. Materials and methods

This research is aimed at evaluating methods that determine an ABC as a basis for setting annual catch limits. Twenty-five methods for determining OFLs and modifying them using ABC control rules are evaluated, including nine that have been used in the management of U.S. fisheries (M1–M9), 12 alternative methods (A1–A12), and four reference methods that can be used to comparatively assess the performance of the other methods (R1–R4).

The methods are classified as follows: (1) those that rely on a time series of recent catch ("catch-based methods"); (2) those that adjust historical catches using assumptions about historical depletion and life history characteristics ("depletion-based methods"), and (3) those that rely on current estimates of absolute abundance ("abundance-based methods"). Methods within these classes can be further distinguished into those methods that dynamically update with current information on depletion and those that remain static. The following section describes the specific methods selected for evaluation (see Table 1 for a list of all methods). The data requirements of each method tested are summarized in Table 2, and their detailed description can be found in Appendix B.

These methods are subject to modification by two types of ABC control rule. The first is no downward adjustment. For example, methods M1–M3 are catch methods for which ABC equals the OFL. The second type of ABC control rule uses a simple scalar approach in which a point value produced by a method (e.g., the median outcome of DB-SRA or DCAC) is multiplied by a factor. These scalar factors differ depending on a broadly defined characterization of scientific uncertainty for different groups of stocks (e.g., alternative methods A1, A2 and A7–A12 make use of 75% and 100% scalars).

2.1. Methods evaluated in this study

2.1.1. Catch-based methods

Catch-based methods have generally been employed where insufficient data exist for determining an OFL using more sophisticated methods. For example, the U.S. Southeast and Mid-Atlantic Fishery Management Councils currently apply catch-based methods to dozens of stocks. The South Atlantic Fishery Management Council (SAFMC) has adopted two quantitative approaches to ACL-setting that are simulation tested: the OFL is set to the third highest landings over the last ten years or to the median landings over the last ten years (SAFMC, 2011). The Mid-Atlantic Fishery Management Council has adopted an OFL for Atlantic Mackerel that is the median catch from the last three years (MAFMC, 2010; NMFS, 2011). These approaches stem from the work of Restrepo et al. (1998) who suggested the use of average catches with a downward adjustment based on uncertainty about stock status, although these implementations do not include a downward adjustment. All three of these methods are tested: the median catch over the most recent three years (M1), the median catch over the most recent 10 years (M2), and the third-highest catch over the most recent 10 years (M3).

Other catch-based methods that have been proposed attempt to introduce dynamic updates of simple catch-based control rules based on generally subjective scoring systems, such as the Only Reliable Catch Stocks (ORCS, Berkson et al., 2011) method and Productivity–Susceptibility Analysis (PSA, Patrick et al., 2009). Both of these approaches use biological and fishery characteristics to calculate a single catch value. Berkson et al. (2011) identify a possible means of using the outcome from ORCS to categorize stocks into exploitation levels. Each level leads to a different multiplication of interquartile mean catch (the average of all catches greater than the 25th percentile and less than the 75th percentile) that is selected as a proxy for the OFL or ABC. PSA has been suggested as a basis for an ABC control rule that increases the precautionary buffer with increasing vulnerability of the stock (Berkson et al., 2011). Unfortunately, it proved difficult to test these approaches due to an inability to simulate the subjective scoring systems in a defensible way. The success of the methods is likely to be determined by how they are implemented, so we decided to omit them from the comparative performance analysis.

Instead of simulating these subjective methods we tested a control rule similar to that proposed by Berkson et al. (2011). This control rule dynamically scales a catch-based OFL according to periodic estimates of depletion. The OFL is set to half, equal or twice the interquartile mean catch when current biomass is considered to be less than 20% of unfished, greater than 20% and less than 65% of unfished, and greater than 65% of unfished levels, respectively. In lieu of a subjective scoring system to estimate depletion, we test the performance of the catch scalar methods using imperfect knowledge of simulated current depletion. An imperfect estimate of depletion was simulated by calculating the current level of stock depletion (current biomass divided by unfished biomass) and then adding error according to specified levels of bias and imprecision. This method (referred to as "Depletion Adjusted Catch Scalar", DACS) represents a very simple approach to modifying an OFL using coarse subjective information about current stock levels. We test the DACS method with two ABC control rules: 75% and 100% scalars (methods A1 and A2).