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Research Paper

A multispecies catch-ratio estimator of relative stock depletion

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ABSTRACT

A simple approach is described that uses the ratio of catches among a reference and a target stock to estimate their relative depletion. The catch-ratio estimator was simulation tested to identify conditions under which it can be expected to provide precise and unbiased estimates of relative depletion. The catch-ratio estimator is strongly affected by diverging catch reporting rate and catchability among reference and target stocks. Outside of these issues, the approach is unbiased for a range of life-history characteristics, temporal patterns in exploitation rate and changes in the age vulnerability to fishing. Coupled with the depletion estimates of a data-rich stock, the catch ratio estimator can be used to infer depletion of a data-limited stock without an assessment.

1. Introduction

In many fisheries only historical catch data are available. It has been claimed that these data alone may be interpreted in terms of stock depletion (e.g. Kleisner and Pauly 2011; Martell and Froese 2012; Worm et al., 2006). This is a questionable proposition since in most fisheries catch trends are determined, often strongly, by many factors other than depletion including changing fishing effort, fishing efficiency, overlap of the stock with fishing, species targeting and management regulations (Branch et al., 2011; Carruthers et al., 2012; Pauly et al., 2013). It is for good reason that in many data-rich settings, fishing effort data in addition to catch data are used to construct indices of relative abundance, and it is considered best practice to apply statistical approaches to correct for factors that affect catchability (fishing mortality rate per effort) such as fishing gear, season, location and species targeting. The extraction of trends in relative abundance from fishery catch and effort data typically relies on generalized linear modelling and is referred to as catch-per-unit-effort standardization (CPUE standardization) (Maunder and Punt 2004; Maunder et al., 2006; Campbell 2015).

Let us assume that catch data alone cannot be interpreted in terms of stock depletion. This is highly problematic because depletion is arguably one of the most informative quantities for managing fisheries (Hilborn and Walters 1992) but is unavailable for the majority of the worlds fisheries (Costello et al., 2012). Without independent surveys of absolute or relative abundance, without effort data or catch composition data (age or size samples), a conventional stock assessment is not feasible and these fisheries are considered ‘data-limited’ (Punt et al., 2011; Newman et al., 2015). Many approaches have been suggested for the management of data-limited species that use depletion estimates as inputs, for example Depletion-Corrected Average Catch (DCAC, MacCall 2009) and Depletion-Based Stock Reduction Analysis (DB-SRA, Dick and MacCall 2011). This is paradoxical since depletion is a principal output of a data-rich assessment and the lack of this information currently defines a data-limited fishery. Recently simulation testing has revealed that very simple management rules that use current stock depletion and historical catch data could perform well over a range of fishery and stock life history types (e.g. MCD by which catch limit recommendations are twice mean average catches multiplied by the current depletion estimate) (Harford and Carruthers 2017). However, this seems theoretical at best since similarly to DCAC and DB-SRA, these approaches require an estimate of stock depletion that is derived by unspecified means.

A general approach to the data-limited assessment problem has been proposed in which information from an assessed data-rich species may be borrowed to inform data-limited species, a so-called Robin Hood approach (Punt et al., 2011). In this paper a simple multispecies catch-ratio approach is described and simulation tested that uses only historical catch data to infer a time-series of relative depletion (the fraction of target stock depletion relative to a reference stock depletion). In situations where a time series of depletion is available for a reference stock this relative depletion can be used to infer the depletion of the target stock (a Robin Hood approach). Although the focus of this paper is depletion estimation, the concept is similar to that proposed by Maunder and Hoyle (2007) for inferring skipjack tuna abundance using purse-seine catch ratios and a stock assessment of bigeye tuna.

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Table 1
The ten simulation exercises. In each simulation exercise 2000 simulations were undertaken where parameters for reference and target stocks were drawn independently from uniform distributions. These included natural mortality rate M, the lognormal standard deviation in catch observations s, the mean fraction of catches reported b, the annual percentage change in catchability of the reference stock g, the extent of dome-shape in vulnerability in the final year d, the position of age at maximum vulnerability relative to age at 50% maturity v, and percentage annual change in fishing effort over the last 32 years of the historical simulation w and stock depletion D (spawning biomass relative to unfished). Additionally catches could become progressively biased towards b over time where a binary switch $u = 1$. Parameters for age at 50% maturity A and the von Bertalanffy growth parameter K were derived from empirical relationships with M (Fig. 1). Where applicable, parameters specific to reference and target stocks are denoted by superscripts R and T.

Simulation exercise	Exercise-specific	All exercises
S1. Precise catch observations, constant catchability, flat-topped vulnerability and maximum vulnerability at age at 50% maturity		*Population dynamics* $M \sim$ U(0.1, 0.5) $A = f(M)$ $K = f(M)$ $D \sim$ U(0.1, 0.6) *Fleet dynamics* $w \sim$ U(-5, 5) $g = 0$ $d^R = d^T = 1$ $v^R = v^T = 1$ $u^R = u^T = 0$ *Catch observations* $b \sim$ U(0.5, 2) $s \sim$ U(0.05, 0.15)
S2. Diverging catchability	$g \sim$ U(-2, 2)	
S3. Imprecise catch observations	$s \sim$ U(0.15, 0.25)	
S4. Imprecise catch observations, normalized by mean of first five years ($n = 5$, Eqn. 6)	$s \sim$ U(0.15, 0.25)	
S5. Increasingly dome-shaped vulnerability on reference stock	$d^T \sim$ U(0, 1)	
S6. Increasingly dome-shaped vulnerability on target stock	$d^R \sim$ U(0, 1)	
S7. Changing age of maximum vulnerability of reference stock.	$v^R \sim$ U(0.5, 1.5)	
S8. Changing age of maximum vulnerability of target stock.	$v^T \sim$ U(0.5, 1.5)	
S9. Reference stock catches start unbiased and tend to b bias levels	$u^R = 1$	
S10. Target stock catches start unbiased and tend to b bias levels.	$u^T = 1$	

2. Methods

2.1. Theory

If a fleet f is defined as a fishing operation where catchability q is constant over time (q can differ among species), in any time step t the ratio Δ of catches C of a target stock T, relative to a reference stock R, is equal to the ratio in their biomass (B) multiplied by the ratio of their catchabilities:

$$\frac{C_{f,t}^T}{C_{f,t}^R} = \Delta_{f,t} = \frac{q_{f,t}^T B_t^T}{q_{f,t}^R B_t^R} \tag{1}$$

Nominal fishing effort (E) is not included in this equation since it is identical for both stocks for the same fleet and time step.

Eq. (1) can also be expressed in terms of the ratio of stock depletion among target and reference stocks. Here depletion D is defined as the fraction of unfished spawning biomass $B0$ at time t. For example, depletion of the reference stock is given by:

$$D_t^R = \frac{B_t^R}{B0^R} \tag{2}$$

Given Eqs. (1) and (2), the ratio of catches among the target and reference stocks is proportional to the ratio of depletion among reference and target stocks:

$$\frac{C_{f,t}^T}{C_{f,t}^R} = \frac{q_{f,t}^T B0^T D_t^T}{q_{f,t}^R B0^R D_t^R} = \alpha_{f,t} \frac{D_t^T}{D_t^R} \tag{3}$$

For completeness the catchability coefficients q and the α term include the subscript for time period t. This underlines a key requirement, that the catchabilities can vary over time but across time periods their ratio q^T/q^R must remain constant for α to remain constant thereby ensuring the catch ratio (left hand term) is proportional to the depletion ratio D^T/D^R during any time period t.

Depletion *trend* of the target stock can be inferred from Δ and a depletion estimate for the reference stock (arising from a stock assessment for example):

$$\widetilde{D}_t^T = \Delta_{f,t} D_t^R = \alpha_{f,t} D_t^T \tag{4}$$

This depletion estimate $\widetilde{D}$ is not scaled to be a fraction of an unfished level. It follows the relative depletion vector requires normalization, for example by division by the first year (assuming the first year is unfished):

$$\hat{D}_t^T = \frac{\widetilde{D}_t^T}{\widetilde{D}_1^T} \tag{5}$$

Alternatively, to lessen variance in the estimator due to catch observation error, depletion in the final year N, could be calculated from the mean ratio of depletion in the n initial and n final years:

$$\hat{D}_N^T = \frac{\sum_{i=N-n+1}^{N} \widetilde{D}_i^T}{\sum_{i=1}^{n} \widetilde{D}_i^T} \tag{6}$$

This is referred to as the ‘mean catch ratio estimator’ herein.

The requirement for normalization highlights a practical and theoretical limitation of the approach: that catches must be available from ‘unfished conditions’ for both reference and target stocks.

The catch ratio estimator proposed here is conceptually simple. If for a given fleet, catches of one stock are declining faster than another stock and the ratio of their catchabilities can be assumed to be constant over time, per Eq. (3) the different trends can only be explained by the relative trend in vulnerable (or exploitable) biomass. The approach is theoretically consistent with the wider practice of catch-rate standardization in which it is assumed that catch rates are proportional to abundance.

2.2. Simulation testing

It is worthwhile investigating the robustness of the catch-ratio approach under conditions that are typical in data-limited fisheries where it is most likely to be applied. Ten simulation exercises (S1–S10) were undertaken to evaluate the effect of imprecise catch observations,