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Developing risk equivalent data-rich and data-limited harvest strategies

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ABSTRACT

Several fisheries jurisdictions are aiming to achieve risk equivalency (here defined as the probability of a stock being depleted below a limit reference point or not being maintained at a target reference point) irrespective of the stock assessment method used to provide management advice and the amount of data available. Risk equivalency is implicitly required under the USA Magnuson-Stevens Act, while in Australia it is an explicit component of the Australian Commonwealth Government's Harvest Strategy Policy. Risk equivalency is well understood, but few fisheries have attempted to implement it. The Australian Southern and Eastern Scalefish and Shark Fishery (SESSF) is the only Australian fishery that has explicitly done so, albeit in a semi-arbitrary manner. Assessments and associated harvest strategies are placed into tiers from data-rich to data-limited. There are also meta-rules that control how much catch limits can change from one year to the next, and buffers by tier to achieve risk equivalency. Here, the SESSF tier system was evaluated in an ecosystem context using Management Strategy Evaluation. Two buffer systems were considered, the current SESSF system and a system inferred from how the Acceptable Biological Catches are set for the USA west coast groundfish fishery. Harvest strategies for all tiers were capable of moving productive stocks so their biomasses lay between the limit and target reference points. The USA buffer system was more conservative than the SESSF system, and achieved the fastest recovery for depleted stocks. The latter system led to slightly lower total catches, but was closest to achieving risk equivalency across the tiers. The USA buffer system led to biomass trajectories most similar to those when the system was managed so that biomass moves as rapidly as possible to its target reference point.

1. Introduction

Over the last few decades, jurisdictions such as Australia, New Zealand, Canada, and the USA have implemented a process of managing target species using harvest strategies (Butterworth, 2007; Smith et al., 2013): that is, a system of monitoring, assessment and harvest control rules that are used to determine management actions for a fishery. The need to make such recommendations for many stocks with differing levels of data availability has led to the development of tier systems in which species are categorized from data-rich to data-poor, with harvest strategies developed for each category of species. Tier systems are used in some USA federal fisheries, the Australian Southern and Eastern Scalefish and Shark Fishery (SESSF), and by the International Council for the Exploration of the Sea (ICES) (see review in Dichmont et al., 2015).

'Risk equivalency' is defined in the Australian Commonwealth Harvest Policy (HSP) as "ensur(ing) that the stock stays above the limit biomass level at least 90% of the time" (DAFF, 2007). The SESSF is the only Australian fishery that has formally placed harvest control rules (HCRs) and their associated assessment methods into tiers. The tiers arose due to the multi-species nature of the SESSF and the large number (34) of Total Allowable Catches (TACs) that are set within this fishery. Within each tier, a set of "buffers" or "discount factors" are used to attempt to equalize risk between tiers (Fay et al., 2012). These buffers are applied to the assessment-produced target catch or effort to account for uncertainty in the

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assessment and hence the Recommended Biological Catch (RBC). The intention is to reduce the final TAC determined from high-risk data-poor HCRs to reflect the bias and uncertainty associated with the assessment method and HCR being applied. Similarly, in the USA, the buffer between the Overfishing Limit and the Allowable Biological Catch reflects the extent of scientific uncertainty and differs between the tiers and species. The buffer is a function of the extent of assessment uncertainty and the risk tolerance given uncertainty (e.g. Prager and Shertzer, 2010; Punt et al., 2012; Shertzer et al., 2008).

The application of buffers is one means of trying to account for uncertainty associated with the HCR. An additional common tool used in Australia and internationally is Management Strategy Evaluation, MSE (Butterworth, 2007; Punt et al., 2016). The IWC (e.g., Punt and Donovan, 2007), South Africa (e.g., Plagányi et al., 2007; De Oliveira and Butterworth, 2004), Australia (e.g., Wayte and Klaer, 2010; Dichmont and Brown, 2010; Fay et al., 2011; Klaer et al., 2012), USA (e.g., Punt et al., 2012; Hurtado-Ferro and Punt, 2014) and ICES (e.g. ICES, 2013, 2014) have all used MSE to try and ensure that their HCRs are robust to model, assessment and implementation uncertainty. Dankel et al. (2015) go further, including uncertainty in the HCR itself.

Many of the HCRs and their associated assessment methods (i.e., harvest strategies) that define a tier for the SESSF have been tested using MSE. For example, MSE was used to evaluate several 'data-rich harvest strategies' for the eastern Australian gemfish stock, *Rexea solandri* (Punt and Smith, 1999). Results from that evaluation helped form the basis of the SESSF tier 1 HCR. MSE has also been used to evaluate an average-length-based HCR, defined as the SESSF tier 3 HCR, which performed well for demersal trawl species exhibiting reasonably high productivity (Klaer et al., 2012). Variants of the tier 3 HCR have also been compared/evaluated, which showed that appropriate values for the control parameters (of the HCR) were species-specific, and related to parameters such as the steepness of the stock-recruitment relationship and natural mortality (Fay et al., 2011). In addition, work in the SESSF has also showed that the performance of each HCR varies among stocks. However, to date no MSE analyses has included the currently implemented buffers (Fay et al., 2012; Little et al., 2014).

The first four tiers (or aspects of them) in the recently developed ICES tier (termed "categories") system were evaluated using MSEs (ICES, 2013, 2014; STECF, 2015), determining performance for alternative life histories and stock status (e.g., well managed or over exploited). The choice of buffer size for the USA tier system for the Bering Sea and Aleutian Islands crab stocks has also been evaluated, assuming a range of life histories and information content (Punt et al., 2012). The results were used by the North Pacific Fishery Management Council to establish default buffers for its more data-rich tiers.

The majority of these MSEs performed their evaluations in a single species context (with the exception of STECF (2015), which used Ecopath with Ecosim to provide some long-term perspectives in a multi-model comparison of the implications of alternative fishing mortality levels). In addition, most MSEs did not evaluate their tier system with candidate risk buffers (except Punt et al., 2012). Considering the performance of HCRs across a range of species life history types and within a multi-species or ecosystem context still remains relatively rare. In this paper, we use an ecosystem model that was modified for the SESSF to evaluate its four-tier system for a range of representative species, with the emphasis on evaluating the efficacy of existing buffer systems in the context of achieving risk equivalency. Analyses consider the SESSF buffers as well as a set of buffers inferred from how buffers are set for the USA west coast groundfishery. The effect of constraints on the extent of permitted inter-annual change in RBCs is also evaluated.

2. Methods

2.1. Operating model

At the core of an MSE is the operating model, which describes the dynamics of the system of interest. This is then sampled (in much the same way the real world is sampled) using a sampling model (detailed below).

The end-to-end ecosystem model, Atlantis for South Eastern Australia (Atlantis-SE; Fulton et al., 2014) formed the operating model for the MSE outlined here. It was modified (and henceforth referred to as Atlantis-RCC) to generate more realistic (smoother) size-composition data. Atlantis-RCC is a 3-D box model: regions (Fig. 1) are based on the (i) physical and (ii) ecological properties, and (iii) distribution of the water bodies and geomorphology of south eastern Australia (summarised in IMCRA, 1998; Butler et al., 2001; Lyne and Hayes, 2005; Fulton et al., 2007). The maximum modelled depth is 1800 m (waters deeper than this are treated as an open boundary).

The physical environment for Atlantis-RCC included ocean currents and water column properties (e.g. temperature and salinity). Vertical and horizontal exchanges between boxes, as well as physical properties such as temperature and salinity, were taken from the data-assimilated version of the global ocean model OFAM (Oke et al., 2005).[1]

Atlantis-RCC includes the food web described by Fulton et al. (2007, 2014) (summarised in Table S1 here). It was initialised in 1980 and run under historical fishery catches and known environmental drivers until 2005, and pre-specified harvest strategies applied thereafter. To do this a new set of initial conditions was needed, as previous updating of Atlantis-SE and Atlantis-RCC had primarily been for the period post 2000. A two-step processes was undertaken to create the new initial conditions. For species with existing assessments, the levels of depletion identified by Morison et al. (2012) were used to infer the 1980 biomass based on the 2005 biomass estimates from the most recent (updated) version of Atlantis-SE (Fulton et al., 2007). For all other groups, century long historical simulations (1910–2010) run using an earlier version of Atlantis-SE (Fulton et al., 2007) were used to calculate the relative (simulated) biomass in 1980 versus 2005. This scalar was then applied to the 2005 biomasses from the most recent (updated) version of Atlantis-SE (Fulton and Gorton, 2014) to get the 1980s biomasses to use with Atlantis-RCC.

One set of biological parameter values (e.g., values for non-predation mortality rates, physiological, consumption and growth rates, habitat preferences, movement rates) was used for a species (or functional group), unless the species (or functional group) was assumed to have multiple stocks – in which case fecundity, background mortality and diet connection strength varied among stocks (Supplementary material, Table S1).

The single size-at-age for each vertebrate group in Atlantis-SE varies through time and among locations, based on available prey and resulting realised growth. Nevertheless, the tracking of "average individuals" used in Atlantis was very coarse compared to that of single-species stock assessments applied in Australia. As a result, it was causing problems when trying to apply tier 1 assessment methods to data simulated using Atlantis. Consequently, multiple growth "morphs" were used in Atlantis-RCC (c.f., Punt et al., 2001; Methot and Wetzel, 2013) for all main SESSF species (Table S1). Each morph followed a different growth trajectory so that there was variation in size-at-age within a cohort at each location. This is

[1] The database used is available at http://www.bom.gov.au/bluelink/and SPINUP6 from http://www.marine.csiro.au/ofam1/.

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