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An evaluation of the performance of a harvest strategy that uses an average-length-based assessment method

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ABSTRACT

The average length of the catch has long been used as a simple indicator of stock condition. Previous studies have evaluated the fishery conditions and species' biological characteristics where such an indicator performs best. This study uses a management strategy evaluation framework to test the combination of an average-length-based assessment with a target- and limit-based harvest control rule in terms of achieving specific long-term management objectives. Results show that the average-length-based harvest strategy performs acceptably well for typical Australian demersal temperate trawl species with relatively high productivity. It is essential that the assessment takes the variability in length-at-age into account for this harvest strategy to work effectively.

1. Introduction

Agencies charged with managing fisheries are increasingly required to make decisions in data-limited situations. Provision of scientific advice in many such instances is often made using the results of simple indicator-based assessments that relate an empirical data-based quantity to an underlying stock status condition. Indicator-based assessment methods and associated harvest control rules have been successfully implemented in many commercial fisheries worldwide (e.g., Cape hake off Namibia, New Zealand rock lobster (Butterworth and Punt, 1999); SE Australian trawl species (Smith et al., 2008)). An advantage of indicator-based assessments is the very clear transparency between data and assessment rules, resulting in ease of understanding by stakeholders (e.g. Hilborn, 2012). However, rigorous testing of such methods is necessary to evaluate robustness to key assumptions, which, given the simple nature of the methods, tend to be less realistic than those made in more complicated stock assessment methods.

One of the simplest indicators of stock status that can be easily measured is the average length of fish in the catch. Average-length-based assessment methods can be used for stocks where the data or available resources do not permit a full stock assessment, but information is available on the average length of annual catches, annual total catch, and basic biological parameters. A method for using average length to estimate total mortality, Z, was described by Beverton and Holt (1956), in which Z is a function of average length, and growth parameters (von Bertalanffy K and L_∞). Punt et al. (2001a) formally evaluated size-based indicators, and offered cautionary advice on their imprecise, but informative, use as stock depletion indicators.

The Southern and Eastern Scalefish and Shark Fishery (SESSF) is a complex multi-species, multi-gear fishery regulated by the Australian Fisheries Management Authority (Smith and Smith, 2001), managed primarily using annual Total Allowable Catches (TACs) applied to 34 species or stocks (Smith et al., 2008). A comprehensive monitoring system provides information on landed catch quantities, discarding practices, and length- and age-frequencies of retained and discarded fish. Scientific advice for many of the TAC-managed stocks is based on an indicator-based control rule that uses only catch-per-unit-effort (Little et al., 2011), despite the additional biological information that exists for some species. While the development of full stock assessment models for some species is unlikely in the short-term, an opportunity exists for the development of indicator-based assessments and associated harvest control rules that are able to make use of these additional data.

Management objectives for the SESSF are defined by the Australian Commonwealth Harvest Strategy Policy (CHSP; DAFF, 2007). In this policy, a harvest strategy is defined as a plan that specifies the management actions necessary to achieve the defined biological and economic objectives of a fishery. The term 'harvest strategy' (HS) is used throughout this paper; elsewhere the terms 'management strategy' or 'management procedure' have been used for the same concept. The required components of a HS as defined in the

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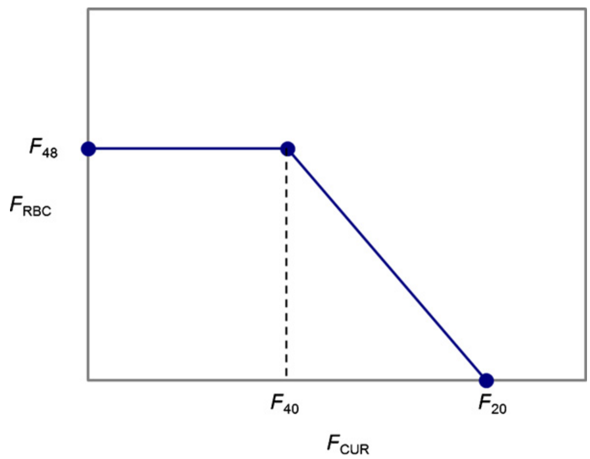

Fig. 1. The harvest control rule used in the average length HS.

CHSP are a data collection scheme, specification of how those data are to be analysed, and a harvest control rule (HCR) that translates the results of the data analyses into management actions (Punt et al., 2005). The aims of a HS in Australia are to: maintain fish stocks, on average, at a target biomass point equal to the spawning stock biomass (SSB) required to produce maximum economic yield (B_{MEY}); ensure fish stocks remain above a limit biomass where the risk to the stock is regarded as too high; and ensure that the stock stays above the limit biomass level at least 90% of the time (DAFF, 2007). The limit biomass is set as half of the SSB required to produce maximum sustainable yield (B_{MSY}). The use of proxies of B_{40} (40% of equilibrium unfished SSB, B_0) for B_{MSY}, and $1.2B_{MSY}$ for B_{MEY} result in a limit SSB reference point of B_{20}, and a target SSB reference point of B_{48}. Stock status in any particular year is defined as the ratio of that year's SSB to B_0.

Extension of an average-length-based assessment into a formal HS, and testing this HS for a variety of scale-fish species with different biological characteristics and current stock status levels using a management strategy evaluation (MSE; Smith et al., 1999; Bunnefeld et al., 2011) has not previously been undertaken. An assessment that uses average length (above a reference length) and biological information to calculate current fishing mortality is outlined. This rapid assessment method is combined with a HCR to form a HS that is used to set a sustainable catch quota. MSE is used to evaluate the HS relative to the management objectives defined by the CHSP for three example species with different life histories. The robustness of the HS is evaluated using simulations to evaluate the impact of key uncertainties related to biological parameters and initial stock status.

2. Methods

2.1. Harvest strategy

The length frequency of fish at lengths lower than at full selection is difficult to interpret because the exact shape of the selectivity curve is normally unknown. To avoid dealing with selectivity shape, a reference length (L_{ref}) was chosen where full selection could be expected. The assessment uses the average length of the catch above L_{ref} and biological information to calculate current fishing mortality (F_{CUR}). F_{CUR} is then compared to the limit, and break-point fishing mortality levels in the HCR to give F_{RBC}, the following year's intended fishing mortality rate (Fig. 1). This estimate of fishing mortality is used in conjunction with a reference catch to determine the recommended biological catch (RBC) for the following year. The calculation of the reference catch, and the HCR used in the average length HS, are very similar to those used in a currently implemented Australian HS (Wayte and Klaer, 2010), which uses age-composition data to estimate F_{CUR}.

Practical application of the average length HS therefore requires three components: (i) estimation of F_{CUR} by comparing observed average catch length to the expected average catch lengths for a range of fishing mortalities, (ii) application of a HCR that estimates F_{RBC} from F_{CUR}, and (iii) calculation of the RBC using a ratio that includes F_{CUR} and F_{RBC}, and an appropriate estimate of recent catches (C_{REF}).

2.1.1. Estimation of current fishing mortality

The average length method uses a yield-per-recruit (YPR) procedure to calculate the expected average length above L_{ref} of the catch for a range of fishing mortalities. The choice for a suitable offset from the age-at-50%-selection to use as the age corresponding to L_{ref} is species-dependent. The intention is to find a minimum length where full selection could be assumed, so that selectivity shape effects are minimised. It was determined that an offset of two years was appropriate for the species examined. L_{ref} and the length-at-knife-edge selectivity, L_{sel}, are calculated from the von Bertalanffy growth equation to correspond to whole ages, to ensure they do not lie on the boundary of a length class used in the YPR calculations. Mid-year length-at-age is used for the YPR boundaries (i.e. length (age + 0.5)).

$$L_{sel} = \text{length at round}(a_{50})$$

$$L_{ref} = \text{length at } \ (\text{round}(a_{50}) + 2)$$

where a_{50} is the age corresponding to S_{50}, and S_{50} is the length-at-50% selectivity.

Calculation of the YPR-expected average length for a given F (*avlen*) requires assumed values for the von Bertalanffy growth parameters (including the coefficient of variation (CV) of length-at-age), natural mortality, and length of knife-edge selectivity as outlined below.

$$\text{avlen} = \frac{\sum_{L=L_R}^{N_L} \sum_{a=0}^{a_{\max}} Y_a p_{aL} l_L^{\text{mid}}}{\sum_{L=L_R}^{N_L} \sum_{a=0}^{a_{\max}} Y_a p_{aL}}$$

where L_R is the length bin in which L_{ref} lies, N_L is the number of length bins, $a_{\max}$ is the maximum age, l_L^{mid} is the midpoint of length bin L, p_{aL} is the proportion of fish of age a in length bin L, Y_a is the yield in numbers at age a:

$$Y_a = S_a \frac{F}{Z_a} N_a (1 - e^{-Z_a})$$

N_a is the number of fish at age a:

$$N_a = \begin{cases} 1 & \text{if } a = 0 \\ N_{a-1} e^{-Z_{a-1}} & \text{if } 1 \le a < a_{\max} \\ N_{a-1} e^{-Z_{a-1}} / (1 - e^{-Z_a}) & \text{if } a = a_{\max} \end{cases}$$

S_a is (knife-edge) selectivity at age a:

$$S_a = \begin{cases} 0 & \text{if } \ L_a < L_{sel} \\ 1 & \text{if } \ L_a \ge L_{sel} \end{cases}$$

L_a is mid-year female length at age a:

$$L_a = L_\infty^f (1 - e^{-k^f ((a+0.5) - t_0^f)})$$

L^f_∞, k^f and t^f_0 are the von Bertalanffy growth parameters for females, Z_a is total mortality at age a: $Z_a = S_aF + M$, and M is natural mortality. p_{aL} is calculated as:

$$p_{aL} = \begin{cases} \Phi\left(\dfrac{l^{lo}_{L+1} - L_a}{cL_a}\right) & \text{if} \quad L = 1 \\ \Phi\left(\dfrac{l^{lo}_{L+1} - L_a}{cL_a}\right) - \Phi\left(\dfrac{l^{lo}_{L} - L_a}{cL_a}\right) & \text{if} \quad 1 < L < N_L \\ 1 - \Phi\left(\dfrac{l^{lo}_{L} - L_a}{cL_a}\right) & \text{if} \quad L = N_L \end{cases}$$

where l^{lo}_l is the lower bound of length bin L, Φ is the standard normal cumulative density function, and c is the CV of length-at-age.

F_{CUR} is estimated as the F that corresponds to the observed average length of the catch. The calculations are based on the biological parameters for females when there are considerable differences in growth between males and females; otherwise sex-specific calculations are not required.

2.1.2. Harvest control rule

The HCR for calculating the following year's intended fishing mortality (F_{RBC}) is:

$$F_{RBC} = \begin{cases} 0 & \text{if} \quad F_{CUR} \geq F_{20} \\ \dfrac{F_{48}(F_{CUR} - F_{20})}{(F_{40} - F_{20})} & \text{if} \quad F_{40} < F_{CUR} < F_{20} \\ F_{48} & \text{if} \quad F_{CUR} \leq F_{40} \end{cases}$$

This HCR (Fig. 1) incorporates limit, break-point and target fishing mortality levels of F_{20}, F_{40} and F_{48} – the F values that will reduce SSB to 20%, 40% and 48%, respectively, of the equilibrium unfished SSB. The methods of Sissenwine and Shepherd (1987) and Mace (1994), along with assumed values for natural mortality, steepness, selectivity, growth, length-weight and maturity parameters, are used to calculate F_{20}, F_{40} and F_{48}.

2.1.3. Determine C_{REF} and the RBC

Wayte and Klaer (2010) showed that that TACs would be subject to a 'ratchet' or time-lag effect that could result in continual increases or decreases in the TAC over time, even in the absence of a change in stock status, if an average of the most recent few years' catches is used for the reference catch in RBC calculations. This is because the estimate of F_{CUR} depends on more than the most recent few years of catches, especially for long-lived species.

To avoid the ratchet effect in the HCR, C_{REF} is calculated over the years in which the fish cohorts used in the F_{CUR} estimation have been affected by fishing mortality. This implies that the fishery influence is measured over a period of at least the number of fully selected ages, and possibly the maximum observed age, if equilibrium methods are used to calculate F_{CUR}. The maximum age (a_{max}) less the age-at-50%-selectivity (a_{50}) is used as the number of years over which to average the catch in this study (and in practice). The age-at-50% selectivity is calculated using growth parameters from the assumed length-at-50%-selectivity (averaged over fleets as needed), rounded up to the nearest integer. Thus C_{REF} is calculated as:

$$C_{REF} = \frac{\sum_{y=y_{min}}^{y_{CUR}} C_y}{(y_{CUR} - y_{min} + 1)}$$

where $y_{min} = y_{CUR} - (a_{max} - a_{50})$, and y_{CUR} is the current year.

C_{REF} is adjusted according to the ratio of the intended and current exploitation rates to calculate the following year's RBC:

$$RBC = \frac{(1 - e^{-F_{RBC}})}{(1 - e^{-F_{CUR}})} C_{REF}$$

All fishery-induced removals (e.g. discards, catches from other jurisdictions, recreational catches) must be taken into account when setting the annual total TAC from the RBC. Constraints imposed upon the TAC are that it cannot change by more than 50% from year to year, and that it remains the same if the change from one year to the next is less than 10%. These constraints are used to provide some level of consistency for the fishing industry. Wayte and Klaer (2010) also showed that the 50% change limit was required to dampen potentially large inter-annual variations in RBC generated by this HCR.

2.2. Management strategy evaluation

MSE is a simulation technique used to evaluate an entire fishery management system (e.g. Smith et al., 1999; Punt et al., 2001b, 2005). It can be used to explore tradeoffs among management objectives that are obtained by individual harvest strategies. Identification of such tradeoffs is important due to the possibly conflicting aims of maximising economic returns, limiting inter-annual variability in TAC, and maintaining stocks at ecologically sustainable levels.

The MSE comprises a mathematical model of the population dynamics of the system in which fishery operates (the 'operating model'), a data generation module, and an assessment component that implements the HS. The operating model representing the 'true' fish stock is an age-structured multi-fleet population dynamics model, described in detail in Fay et al. (2011). This model was projected for 40 years, and simulated data as required for the harvest strategy being tested were generated each year to represent what would be collected from the fishery. These 'data' were used in the harvest strategy for annual assessment of the fishery and calculation of the following year's TAC, which was then applied to the 'true' population structure.

2.2.1. Example species

The specifications for current stock status and population dynamics used to parameterise the operating model were based on recent full quantitative stock assessments for three major SESSF species: tiger flathead (*Neoplatycephalus richardsoni*; Klaer, 2011), jackass morwong (*Nemadactylus macropterus*; Wayte, 2011), and school whiting (*Sillago flindersi*; Day, 2010). The operating models were therefore consistent with the available historical and biological information (Table 1) on these stocks. These species were chosen to represent three contrasting life-history strategies. Tiger flathead are a moderately long-lived species, with relatively constant recruitment; jackass morwong are also long-lived, but with low recruitment in recent years (Wayte, 2012), while school whiting are short-lived with highly variable recruitment.

Each of these species is exploited by more than one fleet, parameterised using different logistic selectivity ogives. Thus, it is necessary to consider which fleet's selectivity parameters are to be used when calculating the knife-edge selectivity and reference lengths for use in the HS (Table 2). School whiting is caught by a Danish seine and a trawl fleet, with the catch by the trawl fleet roughly twice that of the Danish seine fleet in recent years. However the average length harvest strategy cannot be used with data from the trawl fleet because school whiting are not fully selected at their maximum length by this fleet, thus there is very little catch above the reference length (as the reference length is the length above which fish are thought to be fully selected). The Danish seine

Table 1
Biological parameters for tiger flathead, school whiting, and jackass morwong.

Parameter	Tiger flathead		School whiting	Jackass morwong
First historical year	1915		1947	1915
Last historical year	2008		2008	2008
Number of fleets	4		2	6
Maximum age (year)	20		6	30
Growth parameters	Female	Male	Both sexes	Both sexes
L_∞ (cm)	56.17	45.88	25.01	35.75
k (year^{-1})	0.135	0.132	0.25	0.226
t_0 (year)	−3.678	−5.692	−1.42	−1.171
CV (length at age)	0.103	0.103	0.073	0.107
Natural mortality, M (year^{-1})	0.22		0.51	0.15
Steepness, h	0.67		0.75	0.7
Recruitment variability, σ_R	0.35		0.359	0.6
Length-weight parameters				
a (kg cm^{-3})	0.0000058		0.000013	0.000017
b	3.31		2.93	3.031
Maturity parameters				
Logistic slope	−0.25		−2.0	−1.0
Logistic inflection (cm)	30.0		16.0	24.5

fishery reaches full selectivity at a smaller size, thus there are adequate data available above the reference length. Jackass morwong is exploited by three present-day fleets, of which one, the eastern trawl fleet, takes the bulk of the catch. Tiger flathead are also exploited by three present-day fleets, of which two, the Danish seine and eastern trawl fleets, take about the same amount of catch. The third fleet, Tasmanian trawl, takes considerably less. Scenarios for tiger flathead were run for a reference length derived from each of the eastern trawl or Danish seine fleets, and for a reference length averaged over those two fleets. In the last scenario, the observed average length was also averaged over both fleets.

2.2.2. Scenarios considered

Scenarios were considered as a set of specifications for the operating model, combined with a set of assumptions for the harvest strategy. Two initial stock status level scenarios were considered for each species: the stock was either below or above the target stock size (B_{48}) at the start of the period in which the HS was applied. These levels were obtained by manipulating the initial stock size in the operating model. The below-target and above-target starting SSBs were 35% and 60%, respectively, of the unfished SSB. Scenarios with the assumed length-at-age CV in the HS set equal to zero were also run for all species, to demonstrate the importance of taking this parameter into account.

The base scenarios were all conducted with the HS assuming the correct values for many of the operating model parameters. The values for parameters such as steepness and natural mortality would be uncertain in actual application. A number of robustness test scenarios were conducted to examine the behaviour of the HS when the values for these parameters were mis-specified (Table 3). For these simulations, the values for steepness and natural mortality assumed when applying the HS differed from the base values used by the operating model.

One hundred simulations were conducted for each scenario, with differences between simulations due to observation error in the generated data, and process error in the population dynamics (future recruitment deviations). Summary statistics were combined over all simulations to provide a set of performance measures for assessing scenarios.

2.2.3. Performance measures

The performance of the average length HS was evaluated using plots of the operating model trajectory of relative spawning biomass and catch over time. The comparative performance for each species was evaluated using summary plots of the following six performance measures relating to stock level, catch, and variability in catch:

1. average annual catch over the projection period;
2. average annual catch over the first five years of the projection period;
3. spawning stock biomass (SSB) in the final year relative to unfished SSB;
4. lowest relative SSB in the projection period;
5. catch variability: average absolute percentage inter-annual change in catch (%AAV) over the projection period:

$$\%AAV = 100\frac{\sum_{t=y_2}^{y_f}|C_t - C_{t-1}|}{\sum_{t=y_1}^{y_f} C_t}$$

   where y_1, y_2, and y_f are the first, second and final years of the projection period, respectively, and C_t is the catch during year t; and
6. probability of the SSB going below the limit reference point (B_{20}) during the projection period.

Table 2
Length- and age-at-50% selectivity, and knife-edge and reference lengths used in the average length HS for each species.

Species	School whiting	Tiger flathead			Jackass morwong
Fleet	Danish seine	Trawl	Danish seine	Average	Trawl
S_{50}	17.36	36.5	32.4		27.35
a_{50}	3.26	4.12	2.7		5.24
L_{sel}	16.8	36.2	33.3	34.8	26.9
L_{ref}	20.4	40.9	38.7	39.8	30.1

Table 3
Robustness test scenarios: simulations where the values of steepness, natural mortality and CV of length-at-age assumed by the average length HS mis-matched the base values used by the operating model.

Species	Assumed			Median performance measures					
	M	h	CV	Av catch	5 year av catch	Fin rel SSB	Min rel SSB	%AAV	$P(B<B_{20})$
Tiger flathead	0.22	0.67	0.103	1909	753	0.50	0.28	30	0
	0.22	0.4	0.103	1649	578	0.55	0.32	32	0
	0.22	0.6	0.103	1856	728	0.51	0.29	30	0
	0.22	0.8	0.103	2006	834	0.48	0.26	29	0
	0.15	0.67	0.103	578	559	0.85	0.33	29	0
	0.3	0.67	0.103	2343	2336	0.32	0.06	31	0.25
	0.22	0.67	0.052	2313	1892	0.37	0.11	30	0.18
	0.22	0.67	0.154	800	559	0.77	0.33	30	0
Jackass morwong	0.15	0.7	0.107	1502	1288	0.45	0.26	30	0
	0.15	0.4	0.107	1221	1052	0.55	0.34	31	0
	0.15	0.6	0.107	1420	1243	0.47	0.28	30	0
	0.15	0.8	0.107	1570	1355	0.42	0.24	29	0
	0.1	0.7	0.107	544	593	0.85	0.37	32	0
	0.2	0.7	0.107	1867	1910	0.24	0.08	30	0.25
	0.15	0.7	0.054	1826	1982	0.11	0.03	27	0.58
	0.15	0.7	0.160	113	218	0.99	0.37	35	0
School whiting	0.51	0.75	0.073	1744	1427	0.41	0.22	28	0
	0.51	0.4	0.073	1435	1149	0.53	0.25	33	0
	0.51	0.65	0.073	1703	1375	0.44	0.23	29	0
	0.51	0.85	0.073	1789	1472	0.38	0.21	27	0
	0.4	0.75	0.073	1320	1050	0.56	0.30	32	0
	0.6	0.75	0.073	1932	1702	0.31	0.16	24	0.08
	0.51	0.75	0.037	2084	1979	0.23	0.14	23	0.23
	0.51	0.75	0.109	846	837	0.74	0.38	32	0

2.3. Performance comparison of average length and age composition procedures

The results of MSE-testing a HS that used age composition and catch curve analysis to determine F_{CUR} has been published previously (Wayte and Klaer, 2010). This allowed us to make a direct comparison of the relative performance of the two approaches.

3. Results

3.1. Average length harvest strategy

The below-target school whiting stock was quickly returned to the target level, and stabilised just below this level (Fig. 2a). For the above-target stock, the catch was initially set too high, causing the stock to drop below the target level, but this was soon corrected, and the stock stabilised slightly below the target level (Fig. 2b). When the variability around length-at-age was not taken into account in the HS, the initial catches were set too high, and the stock did not recover (Fig. 2c).

The below-target jackass morwong stock was returned to the target level after about 10 years and maintained close to this level (Fig. 3a). The response is slow because the reference catch is averaged over a large number of years (24) because morwong is a relatively long-lived species. For the above-target stock, current F is estimated to be low relative to the target F, so resulting RBCs are high, but the TAC is constrained by the 50% rule to be less than the RBC, so catches cannot increase as quickly as the HCR demands (Fig. 3b, lower panel). Thus, stock status increases initially before declining again to the target level (Fig. 3b, upper panel). It takes over 30 years for catches to get high enough to reduce the stock to the target level for this scenario (Fig. 3b, upper panel). The HS again performed poorly when variability in length-at-age was ignored (Fig. 3c). In this case, the average length at a given F is calculated to be lower than it should be, because the YPR calculations do not include the larger fish at each age. Thus, F_{CUR} is under-estimated, catches are set too high, and the stock is not maintained near the target level.

The results shown for tiger flathead are those where the reference length was averaged over the two main two fleets, as this scenario led to the best outcomes. The average length HS performed adequately for tiger flathead, with the median projected stock level oscillating around the target level, for both the below- and above-target scenarios (Fig. 4). As for the other species, the scenario where variability in length-at-age is ignored performs poorly.

The performance measures are summarised for each species and starting stock level in Fig. 5. The HS performs satisfactorily relative to the management and policy objectives, with final relative SSB close to the target level, minimum relative SSB above the limit level for most simulations, and the proportion of years in which the spawning biomass goes below the limit reference point during the projection period below 10% for almost all simulations. The least satisfactory aspect of the performance of the HS is that the year-to-year catch variability is very high. The range of final relative SSB levels is also wide for all scenarios.

The results of applying the average length HS when either the assumed steepness, natural mortality, or length-at-age CV differ from those used in the operating model were very similar for all three species, although the differences among scenarios were less pronounced for school whiting (Table 3). Results were most marked for jackass morwong, so only those results are shown in detail (Fig. 6).

The performance of the average length HS was fairly insensitive to the value of the stock-recruit steepness parameter, h. The scenarios with an assumed value of h higher or lower than that used in the operating model all recovered the stock to fairly close to the target level at the end of the projection period. Catches were slightly lower than those of the base scenario for the lowest value of h, and vice versa. Using the wrong value of natural mortality, M, in the assessment however, led to poor outcomes. When assumed M was lower than the true M, not surprisingly fishing mortality

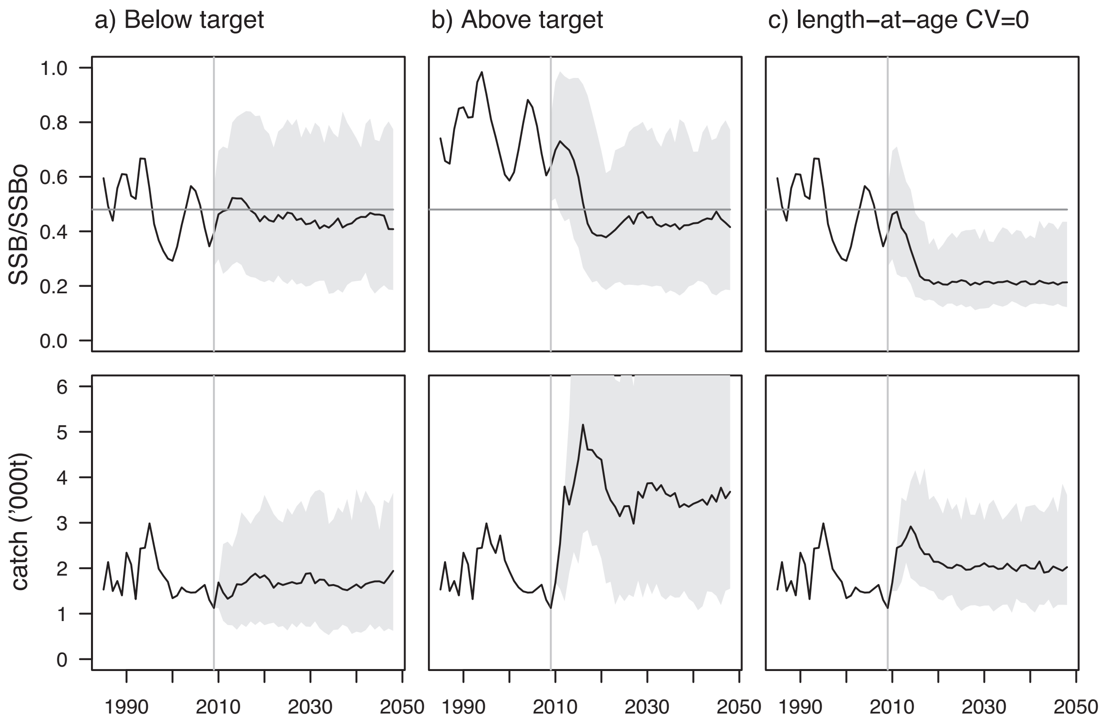

Fig. 2. School whiting 'true' time-trajectories (median, and 2.5 and 97.5 percentiles) of relative SSB (upper panels) and catch (lower panels) for application of the average length HS to scenarios with (a) initial stock status below the target, (b) initial stock status above the target, and (c) with length-at-age CV = 0. The horizontal grey line shows the target relative SSB (0.48) and the vertical grey line indicates the start of the projection period. Only the final 20 years of historical data are shown.

was estimated to be much higher than the true value, so catches were set very low, leading to the relative SSB far exceeding the target level. When assumed *M* was higher than the true *M*, fishing mortality was underestimated, so catches were set too high, and the relative SSB fell to below the target level. Results were also relatively sensitive to the value assumed for the CV of length-at-age. When the CV is underestimated, the catches were set too high and relative SSB fell below the target level, and vice versa.

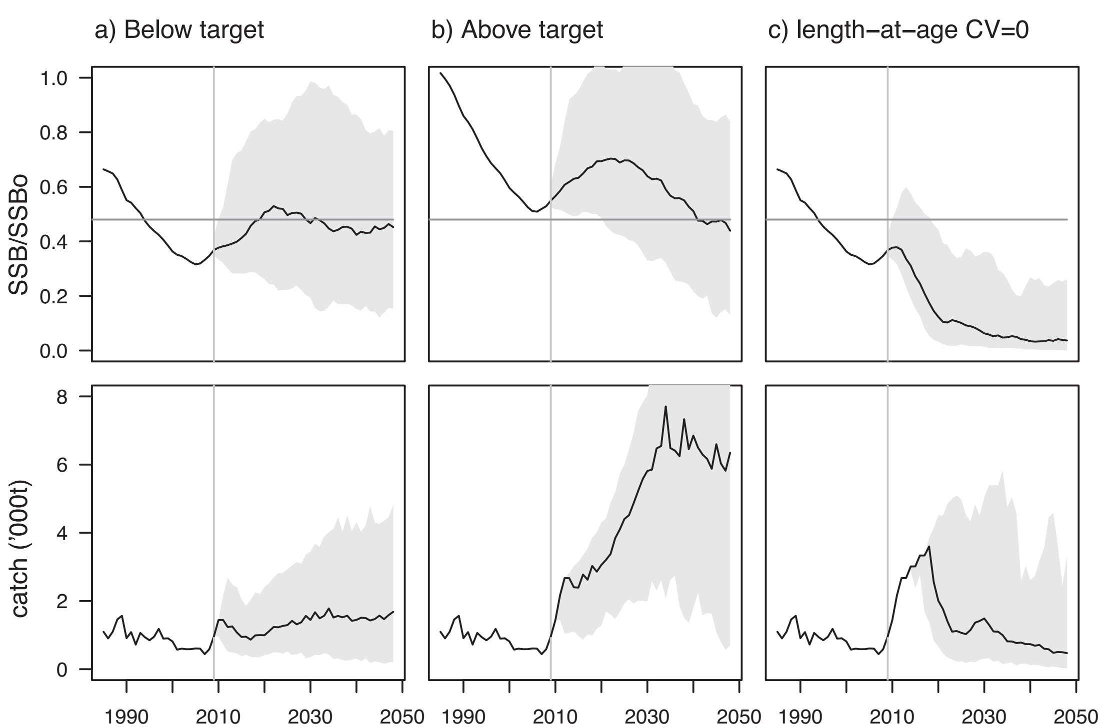

Fig. 3. Jackass morwong 'true' time-trajectories (median, and 2.5 and 97.5 percentiles) of relative SSB (upper panels) and catch (lower panels) for application of the average length HS to scenarios with (a) initial stock status below the target, (b) initial stock status above the target, and (c) with length-at-age CV = 0. Plot symbols are as for Fig. 2.

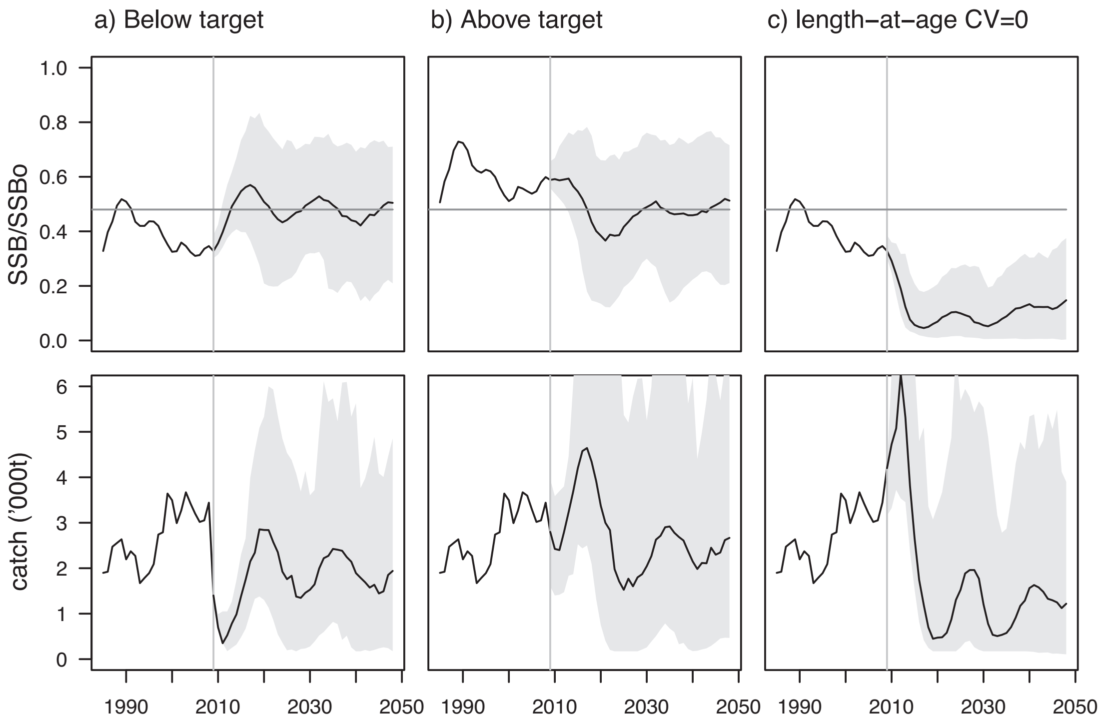

Fig. 4. Tiger flathead 'true' time-trajectories (median, and 2.5 and 97.5 percentiles) of relative SSB (upper panels) and catch (lower panels) for application of the average length HS to scenarios with (a) initial stock status below the target, (b) initial stock status above the target, and (c) with length-at-age CV = 0. Plot symbols are as for Fig. 2.

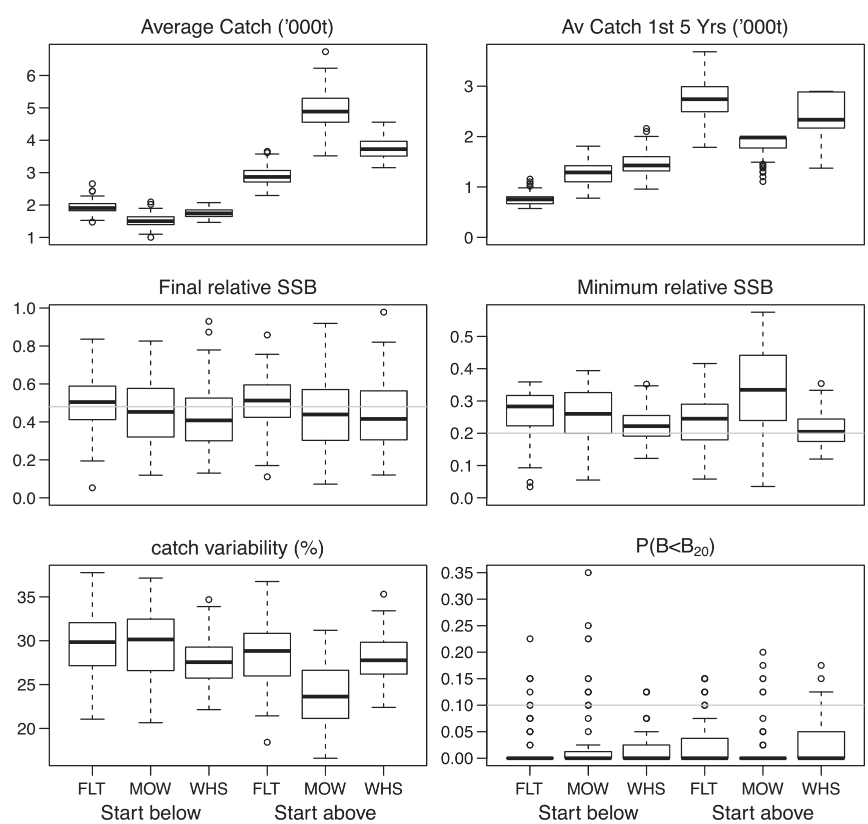

Fig. 5. Box plots summarising the performance measures for the application of the average length HS for all species and initial stock status combinations. The horizontal grey lines in the middle panels show the target and limit relative SSBs, and in the bottom right panel, the 10% probability of the SSB going below the limit reference point. For each scenario, the dark horizontal line shows the median value. The bottom and top of the box show the 25th and 75th percentiles, respectively. The vertical dashed lines show either the maximum or minimum values, or, if there are outliers in the data, they correspond to approximately two standard deviations. Outliers are plotted individually.

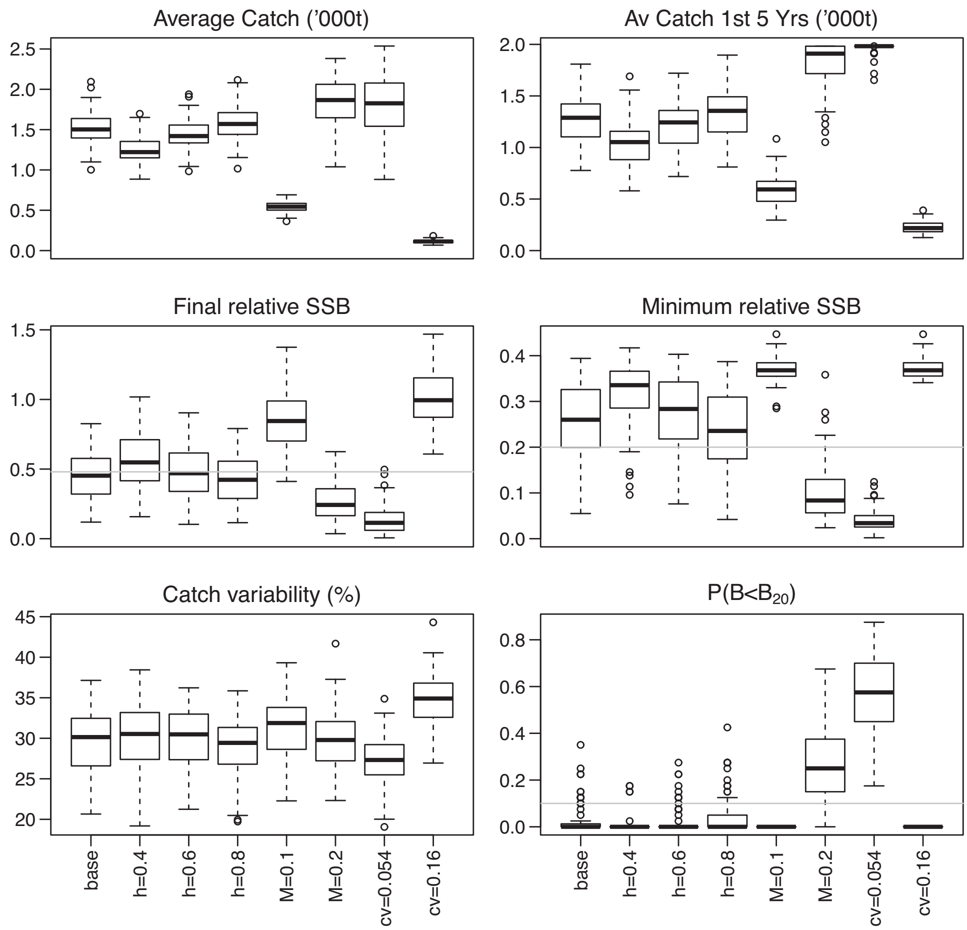

Fig. 6. Box plots summarising the performance measures for the robustness tests for jackass morwong. The below-target initial stock status was used for all scenarios. Plot symbols are as for Fig. 5.

3.2. Comparison with an age-based harvest strategy

Comparison of this HS that uses average length to determine F_{CUR} with one that uses age composition (Wayte and Klaer, 2010) shows that the performances of the two strategies are reasonably similar for most performance measures (Fig. 7). The average length method leads to slightly lower average annual catches and slightly higher final SSB levels. The average length method leads to considerably more inter-annual variability in catches.

4. Discussion

The MSE results show that an average-length-based harvest strategy performs well and can achieve management policy objectives with an acceptable level of risk. Its data requirements are low, and the strategy is simple to implement and to convey to stakeholders. Such a strategy is suited to fisheries with good information on recent catch history (relative to the species maximum age), knowledge of basic biological parameters (growth, natural mortality, steepness), fishery selectivity shape, and a recent representative length frequency sample from the catch.

Cope and Punt (2009) examined the proportion of large-sized individuals in the catch as an indicator of F_{CUR}, and the effect of alternative fishery selectivity, life history traits and stock-recruitment steepness on the utility of the indicator. Their results showed that the ability of the indicator to determine F_{CUR} was most sensitive to the form of selectivity, and the assumed steepness value. They found that there was only sufficient contrast in average size proportions to determine stock status for more productive species when steepness was high. The examination here assumed that selectivity was logistic. The method cannot be used as described if there is reason to believe that selectivity is dome-shaped, because fishing mortality will be over-estimated.

The default steepness assumption used for SESSF assessments is close to 0.75 (Francis, 1993). The stocks examined here either use default values (morwong 0.7 and whiting 0.75), or have an estimated steepness value (tiger flathead 0.62). It is likely, based on the findings of Cope and Punt (2009), that the performance of the average length-based assessment and HCR would be degraded for species with lower steepness. Robustness tests performed here did not show particular sensitivity to low steepness, but testing was not carried out using low steepness values for the true population.

Inclusion of variability in length-at-age in the MSE operating model led us to determine that the method used to calculate F_{CUR} from average length must account for this variability to perform adequately. It is important for the assessment method to better estimate the true age-structure especially for fish at lengths near L_{ref} – i.e. the faster growing fish at ages lower than age at L_{ref}, and the slower-growing fish above that age. Previous simulation studies (e.g. Ault et al., 2005; Cope and Punt, 2009) have not examined this aspect. The values for the CVs of length-at-age used here were based on otolith samples. Robustness testing shows that it is important to use estimates that are likely to be accurate, so values from actual otolith samples would be preferred. If the CV is unknown, a value could be chosen from species with comparable life history.

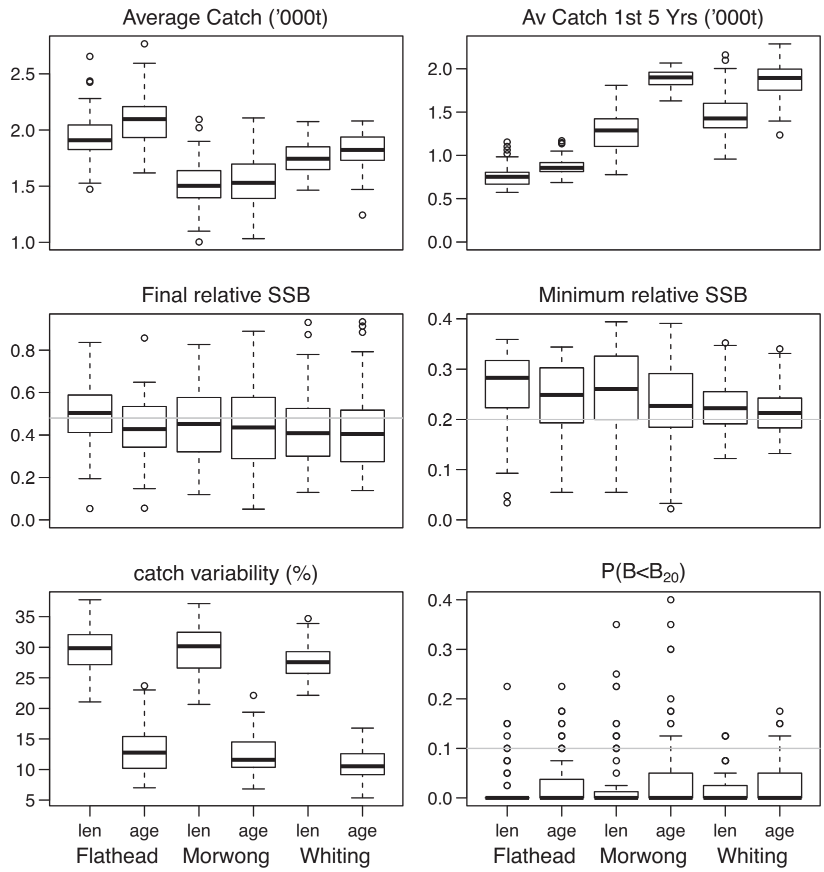

Fig. 7. Box plots comparing the performance measures for the harvest strategies based on average length (len) or age composition (age), for each species. The below-target initial stock status was used for all scenarios. Plot symbols are as for Fig. 5.

Using lengths above L_{ref} rather than lengths of all fish in the catch has the advantage of avoidance of selectivity shape issues. A greater advantage accrues in multi-fleet fisheries where determination of the shape of the combined selectivity below the length of full selection is particularly problematic. A disadvantage is that the influence of the CV of length-at-age is probably more pronounced when only averaging above $L_{\mathrm{ref.}}$ However, is it probably more feasible to measure the CV of length-at-age than the selectivity shape for a data-poor fishery.

Sensitivity to the assumed value for M is a feature of any stock assessment that includes M in its formulation, so this average-length-based procedure is unexceptional in this respect. An appropriate M value needs to be selected for the harvest strategy to perform effectively. For the species tested here, M was either estimated in a fully quantitative stock assessment (morwong, whiting) or from catch-curve analysis from a lightly exploited region (tiger flathead). Robustness tests clearly demonstrate that performance is poor for an inappropriately chosen M value, and that overfishing is more likely if the chosen value is too high. Unfortunately, available M estimates for data-poor species are likely to be highly uncertain, often chosen according to maximum observed age, or from species with apparently similar life history characteristics.

The precision of the observed average length from catches compared to the true population average also affects the ability to determine F_{CUR}. Considerable difference in stock status is indicated over relatively small changes in average catch length. Such behaviour is most likely the cause of higher inter-annual variability of the average length method compared to the age-composition catch curve approach. To alleviate this measurement problem, average weight, or averages of upper percentiles of weight or length distributions have been proposed as alternative indicators that may be subject to less measurement error. However, Punt et al. (2001a) found that identifying which indicators perform "best" was not simple, and depended on the specification of the operating model and sampling procedure. It is obviously important that the indicator is collected from unbiased samples that are representative of the population available to the fishing gear.

Non-representative sampling bias is a problem for any assessment that uses data collected from the fishery, so is not necessarily of special importance to average-length-based procedures. However, it may be more of a problem for data-poor species where the assessment is based on, at worst, data of one type. As data richness increases, the range of available data types also tends to increase, allowing integration and cross-verification within stock assessment procedures. The interaction of indicator precision, sampling error, and the effects on HS performance should be further investigated.

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