Investigating blue mackerel age-estimation error

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New Zealand Fisheries Assessment Report 2011/44
October 2011

Published by Ministry of Fisheries
Wellington
2011

ISSN 1175-1584 (print)
ISSN 1179-5352 (online)

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Ministry of Fisheries
2011

McKenzie, A.; Manning, M. (2011).
Investigating blue mackerel age-estimation error.
New Zealand Fisheries Assessment Report 2011/44.

This series continues the informal
New Zealand Fisheries Assessment Research Document series
that ceased at the end of 1999.

EXECUTIVE SUMMARY

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New Zealand Fisheries Assessment Report 2011/44.

The impact of ageing error was investigated for blue mackerel by implementing an age-based population model, sampling from this population and adding ageing error, then computing catch-at-age and comparing this to the sample without ageing error. As neither the past nor present blue mackerel biomass is known, model runs were done with a range of assumed fishing pressures. Catch-at-age was calculated using both the age-length-key and direct-ageing approaches, for the direct-ageing approach a range of values was assumed for the numbers of otoliths per landing.

For the model runs, the main contributions to the error in estimated catch-at-age are the ageing error bias and variability, increasing with both of these. For a given ageing error and bias, the error increases with the fishing pressure. Under the range of scenarios considered here, there is very little difference in the error between the age-length-key or direct ageing approaches. For direct ageing, the number of otoliths taken per landing make little difference to the error, within the range of sample sizes tested.

Inexperienced blue mackerel readers can be out by 1–2 years compared to experienced readers. The model simulations suggest this will result in an error approximately equivalent to a c.v. of 0.30 or more (with no ageing bias). However, under the revised protocol for blue mackerel ageing, bias is likely to be far less of a problem for all readers, and the additional error introduced far less.

1. OBJECTIVES

The overall objective of the project EMA2005-02 is to investigate the impact of ageing error in the development of catch-at-age from the blue mackerel catch sampling programme (Table 1). This document reports on specific objective 1, which is to investigate the impact of ageing error in the development of catch-at-age from the blue mackerel catch sampling programme for the purpose of stock assessment.

Table 1: Objectives for the project EMA2005-02.

Overall objective:	To investigate the impact of ageing error in the development of catch-at-age from the blue mackerel catch sampling programme.
Specific objective 1:	To investigate the impact of ageing error in the development of catch-at-age from the blue mackerel catch sampling programme for the purpose of stock assessment.
Specific objective 2:	To review and refine protocols for ageing blue mackerel otoliths.
Specific objective 3:	To validate age estimates for blue mackerel.

2. INTRODUCTION

Blue mackerel (*Scomber australasicus*) is a small- to medium-sized schooling teleost inhabiting epi- and mesopelagic waters throughout the Indo-Pacific, including the northern-half of the New Zealand Exclusive Economic Zone (EEZ), where it supports moderate volume commercial fisheries. Blue mackerel was introduced into the New Zealand Quota Management System (QMS) at the start of the 2002–03 fishing year and is managed as five separate Quota Management Areas (QMAs): EMA 1–3, 7, and 10 (Figure 1).

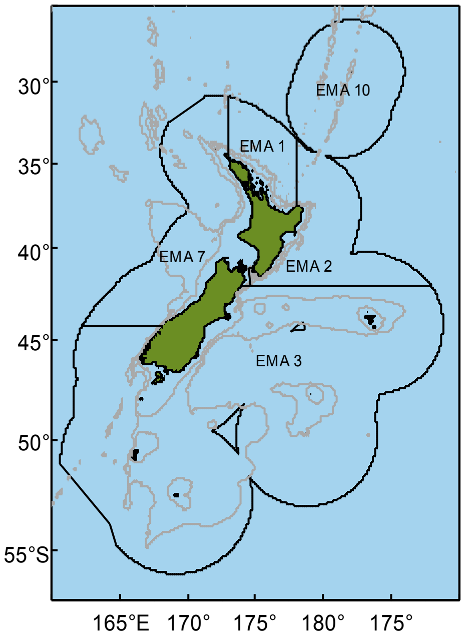

Figure 1: Map of the New Zealand EEZ showing the boundaries of blue mackerel fish stocks. The 250 m and 1000 m isobaths are overlaid in pink.

The total reported commercial blue mackerel catch in the New Zealand EEZ has ranged from 6700 to 12 700 t in the last five fishing years (2004–05 to 2009–10). The largest and most consistent catches over all fishing years were caught in a target purse-seine fishery in the Bay of Plenty (EMA 1) and as bycatch in a target midwater-trawl fishery for jack mackerels (*Trachurus* spp.) in the Taranaki Bight (EMA 7).

There are no stock assessment models for any of the blue mackerel Quota Management Areas (QMAs) of New Zealand (Ministry of Fisheries 2010). The main obstacle to setting up assessment models is the lack of any abundance indices. A standardised CPUE analysis has been undertaken for EMA 7, however the yearly indices showed interaction with area and were thought to show too much inter-annual variation to be treated as abundance indices (Fu & Taylor 2007, Ministry of Fisheries 2010). Consequently, little is known about the status of New Zealand's blue mackerel stocks. No estimates of current or reference biomass or yield are available and it is not known whether recent catches are sustainable or at levels that will allow the stocks to move towards sizes that will support their Maximum Sustainable Yields (Ministry of Fisheries 2010).

However, if in the future suitable abundance indices can be found for blue mackerel, then a stock assessment model could be set up. One of the data components of the stock assessment model would be catch-at-age data, this having two main purposes: (1) to estimate catch selectivities, and (ii) to provide estimates of recruitment for future projections. If the catch-at-age data is inaccurate, either through low precision or high bias, then it may not be useful for this purpose. In early studies blue mackerel otoliths have proven to be difficult to age, and in this report we investigate aspects of the implications of this via simulation modeling.

3. CATCH-AT-AGE DATA

In this section we briefly review previous blue mackerel catch-at-age analyses, with the stocks and years for these in Table 2. The particular aspect of interest in the analyses is the degree of bias, these informing the values to use in the model simulation study.

Table 2: Years for which catch-at-age analyses have been done, denoted by a tick.

Stock	1997–98	2002–03	2003–04	2004–05	2005–06	2006–07
EMA 1	✓	✓	✓	✓	✓	✓
EMA 7			✓	✓	✓	

Morrison et al. (2001) presented an analysis of data collected from the EMA 1 fishery during the 1997–98 fishing year, however they did not carry out any kind of reader accuracy and precision evaluation, and their results cannot be compared with the more recent studies.

Manning et al. (2006, 2007a) presented the results of catch-sampling in EMA 1 and 7 during the 2002–03 and 2003–04 fishing years. In both studies, they found that although blue mackerel otoliths are difficult to interpret, between-reader precision (a between-reader mean coefficient of variation, c.v., of about 14.5%) compared favourably with studies of other species with difficult to interpret otoliths. For example, cardinal fish has a between-reader mean c.v. of 16.7% (Tracey et al. 2000), and giant stargazer a between-reader mean c.v. of 12.4% (Manning and Sutton 2004). They found some evidence of a slight between-reader difference in interpretation of otoliths from older fish, and noted the caveat that the age estimation method they used is unvalidated.

For the 2004–05 and 2005–06 fishing years, catch-at-age analyses were done for both EMA 1 and EMA 7. For the 2004–05 fishing year the between-reader mean coefficient of variation (c.v.) was 9.4% with no evidence of any bias (Manning et al. 2007b). However the c.v. for 2005–2006 was 28.9% with evidence that the relatively inexperienced second reader was ageing two years older then the experienced first reader (Devine et al. 2009). Comparing the experienced first reader with an experienced third reader gave a c.v. of 16.3%.

Lastly, the between reader c.v. for 2006–07 in EMA 1 was 20.3% with the second reader ageing 1–2 years older than the first reader (Smith & Taylor 2011).

Concurrent with these studies the ageing protocol for blue mackerel has been developed further (Manning & Marriot 2011). With the revised protocol the between-reader c.v. was 11.2% (dropping otoliths with readability scores of 4 or 5) or 13.4% (using all observations). There was no evidence of any bias between readers.

In summary, with inexperienced readers it appears a bias of up to two years has occurred in previous ageing studies. This bias appears in ageing the early years, where growth rings are harder to discern, which suggests bias be added in the model in an absolute sense not a relative sense. For experienced readers, the bias is negligible, with between-reader c.v.s reduced under the revised ageing protocol and at a level that is less than comparability hard to age species (though still relatively high compared to easier to read species).

4. METHODS

4.1 Introduction

Blue mackerel catch-at-age distributions in New Zealand are computed using the so-called “age-length key” (ALK) approach. This involves first computing a scaled numbers-at-length (catch-at-length) distribution from data collected from the commercial fishery during each fishing year, then generating an age-length key (a matrix of proportions of fish at each age for each length class in the length distribution) from data collected from the fishery each fishing year, and then applying the key to the catch-at-length distribution (using simple matrix algebra) to yield a scaled numbers-at-age (catch-at-age) distribution (Bull & Gilbert 2001).

An alternative to using the age-length-key approach is direct ageing whereby the age frequency distribution is inferred directly from the age measurement (Bull & Gilbert 2001). The direct age approach is useful if sampling is spread over many months (meaning the age-length key could differ substantially from start to end), but typically needs more otoliths to gain the same precision as the age-length-key approach.

In this specific objective, we investigate the impact of errors in the blue mackerel age estimates used to estimate catch-at-age, either via the age-length-key approach or direct ageing. We do this by applying different process and observational errors to the age-length key using simulation methods. The first step in the analysis is to develop an operating model of blue mackerel catch-at-age. For this purpose the EMA 1 stock is concentrated upon as it has the most data to inform the operating model.

In an initial 2005 simulation model, a re-sampling scheme from known catch-at-age and input length data was implemented with ageing error added in. Catch-at-age was computed from this re-sampled data and compared to the reference distribution (Manning & Marriott 2006). As asked for by MFish in 2007, this simulation model approach was changed to: (a) start with a simple population model for blue mackerel, (b) include recruitment variation, and (c) compare direct-ageing and age-length-key approaches. In this new model, sampling is from the population in the model, ageing error is added, catch-at-age computed, then compared to the sample without ageing error.

In this study, the 2007 simulation model is developed further in order to complete the EMA200502 project. Two bugs were fixed in the code: (i) the simulated age-length-key data were fixed so as to draw approximately an equal number of otoliths from each length bin (previously the otolith were drawn in such as way as to follow the length distribution), and (ii) due to a subtle and odd way the R language treats indexing of lists the simulated direct ageing data were being overwritten with the simulated age-length-key data. Changes to simulation results were minor with these bug fixes. Further developments to the model were:

- In addition to reporting the root mean square error (RMSE) the bias component was also reported (Section 4.3).
- A re-parameterisation of the assumed landings weight distribution (Section 4.5).
- An extended range of simulations for: (i) ageing bias, and (ii) the number of otoliths taken in landings for direct ageing (Section 5).

4.2 The algorithm

In this section the algorithm that is followed for the modelling simulations is outlined. Further details are given in the sections that follow.

Step 1. Initialise population model in an equilibrium with no fishing pressure applied.

Step 2. Update population state.

Step 2.1 Generate stochastic recruitment and update the model state by incrementing ages and apply natural and fishing mortality (F and M).

Step 2.2 Compute the age distribution of the fished population. From this, using the specified length-at-age distribution, compute its length distribution, where the lengths are taken to follow a Von Bertalanffy curve with a normally distributed error (with constant σ - see Table 3) and are capped from below at 1 cm.

Step 2.3 Generate a landings sample from the fished population, where it is assumed that the fish are sampled randomly at length from the fished population.

Step 2.4 Sub-sample otoliths from the landings using the specified sampling scheme (either age-length-key or direct-ageing) and store the results. For the age-length-key approach, the sub-sampled aged otoliths are drawn so that there is approximately equal number of otoliths from each length bin, for direct ageing they are randomly sampled from the length distribution of the fished population.

Step 2.5 If the specified number of simulations (i.e. “years”) is not complete, go back to step 2.1, otherwise go to step 3. In total 500 “years” are simulated.

Step 3. Compute sampled proportions at age and compare with the true fished age distribution (less selectivity) for each of the 500 years.

4.3 Performance measures

The root mean square error (RMSE) was used to compare model and estimated proportions-at-age (after the addition of ageing error). Firstly, the following quantities are defined:

$p_{A,i}$ → proportion for age A, at step i in the simulation
$\hat{p}_{A,i}$ → estimated proportion for age A, at step i in the simulation
N_i → number of steps in the simulation ("years")

Then the mean error at age A over all steps in the simulation is

$$\mathrm{RMSE}_A = \left[(1/N_i) \sum_i \left(\hat{p}_{A,i} - p_{A,i} \right)^2 \right]^{\frac{1}{2}}$$

And the total error of all ages is

$$\mathrm{RMSETOT} = \left[\sum_A \mathrm{RMSE}_A^2 \right]^{\frac{1}{2}}$$

The mean bias at age A over all steps in the simulation is

$$\mathrm{BIAS}_A = (1/N_i) \sum_i \left(\hat{p}_{A,i} - p_{A,i} \right)$$

The total bias over all ages is

$$\mathrm{BIASTOT} = \sum_A BIAS_A$$

The total error and bias are related by

$$\mathrm{RMSETOT}^2 = \mathrm{BIASTOT}^2 + \mathrm{VARIANCE}$$

So the percentage contribution of the bias is

$$100*\mathrm{BIASTOT}^2 / \mathrm{RMSETOT}^2$$

Reported for each model run are RMSETOT and the percentage contribution of the bias.

4.4 The population model

The stock was considered to reside in a single area, with no partition by sex or maturity. Model age groups were 1–43 years. There is a single time step in the model, in which the order of processes is recruitment, ageing, and mortality (natural and fishing).

Natural mortality was estimated at 0.22 yr^{-1} for males and 0.20 yr^{-1} for females by Morrison et al. (2001). As the otolith samples used for these estimations were not from virgin populations these are likely to be overestimates of the natural mortality. An arbitrary and lower common value for males and females of 0.16 yr^{-1} was assumed for the model. Recruitment variability was assumed to be lognormal with a recruitment variability of one, and auto-correlation taking values either 0.0 or 0.2. Stock recruitment follows a Beverton-Holt relationship with a steepness of 0.95, a value which assumes a high resilience to fishing exploitation, and is similar to the value used for jack mackerel (Taylor 1998). Length-at-age Von Bertalanffy growth parameters are both sexes combined for the EMA 1 stock (Manning et al. 2006). Weight-length parameters are for both sexes combined for the EMA 1 stock (Manning et al. 2007a). Maturation is not explicitly modelled, but instead a proportions-mature-at-age logistic ogive is used (Manning, unpublished data). The fishery selectivity is assumed to be logistic with values assumed from previous proportions-at-age analyses (Manning, unpublished data). The model biological parameters are summarised in Table 3.

Table 3: Fixed biological parameters used by the model.

Natural mortality	M	0.16 yr^{-1}	Length-weight	a	3.34×10^{-6}
Recruitment variability	σ_R	1	[W(gm) = a $L(cm)^b$]	b	3.4058
	ρ	0.0, 0.2	Maturity ogive	a_{50}	3.23
Steepness parameter for Beverton-Holt	h	0.95		a_{95}	3.46
Von Bertalanffy length-at-age	L_∞	52 cm	Selectivity ogive	a_{50}	5
	k	0.15 yr^{-1}		a_{95}	2
	t_0	-3.19 yr			
	σ	2.58 cm			

4.5 Parameterising the landings distribution

Typically catches for a fishery follow a lognormal distribution, with many low to middle catches and occasional large catches. However sampling for blue mackerel is based on landings, and these tend to target the larger landings, so the distribution need not necessary be lognormal.

In previous simulations a lognormal distribution was assumed for the landings distribution, but plotting the EMA 1 landings indicates that a normal distribution is a better choice (Figure 2). Hence for the simulations a fitted normal distribution was used with a mean of 143.4 t and a standard deviation of 84.3 t, capped at 0 and 400 t.

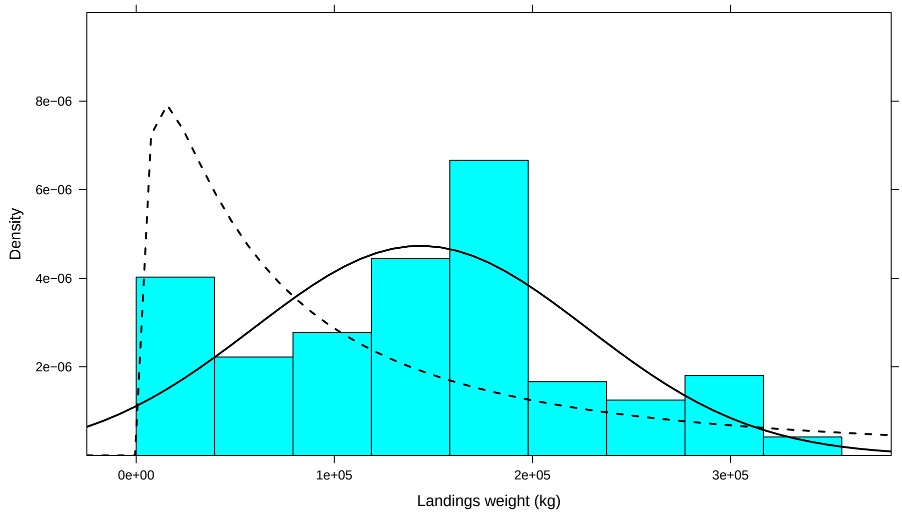

Figure 2: The sampled landings weight distribution for EMA 1 with a fitted lognormal distribution (dashed line) and a fitted normal distribution (solid line). Sampled landing weight data is from the fishing year 1997–98 and the fishing years 2002–03 through to 2006–07.

5. MODEL RUNS

There are no stock assessments for any of the blue mackerel QMAs of New Zealand, and no estimates of current biomass, or exploitation rate. In the model simulations a range of fishing pressures is assumed instead.

Four model runs were made, these being differentiated by the assumed fishing pressure and auto-correlation for recruitment (Table 4). Both direct age sampling (with 50 otoliths per landing) and age-length-sampling were implemented (Table 5). For each model run, seven different bias and ageing error variation scenarios were implemented for the otolith ageing (Table 6).

Another set of runs was done in which ageing bias was increased from one to two, and for the direct ageing, 25 or 100 otoliths were taken for each landing instead of 50.

All models were run for 500 steps ("years") from the initial equilibrium population state.

Table 4: Model runs at fishing pressure F, with ρ auto-correlation for recruitment variability.

Specification	F	ρ
R1	0.10	0.20
R2	0.32	0.20
R3	0.10	0.00
R4	0.32	0.00

Table 5: Sampling schemes. Number of landings sampled in a year (Ns), number of length-frequencies per landing (NLF), and number of otoliths per landing (No).

Sampling scheme	N_{S}	N_{LF}	N_{O}
"Direct"	25	0	50
"ALK"	25	200	20

Table 6: Ageing error specifications. The added error is normally distributed with mean μ and coefficient of variation c.v. Lengths are assumed to be measured with no bias and a c.v. of 0.01.

	Age error	
Scenario	μ	c.v.
1	0	0.00
2	0	0.05
3	0	0.10
4	0	0.30
5	-1	0.05
6	-1	0.10
7	-1	0.30

6. RESULTS

There is very little difference between the results for the direct ageing and age-length-key approaches (Figure 3 and Figure 4). The only noticeable difference is for RMSETOT when the bias is zero and the ageing error c.v. is either 0.0 or 0.05. Otherwise the error contribution to RMSETOT is dominated by the contribution from the ageing error, rather than from differences in the catch-at-age method.

There is little difference between the model runs R1-R4 until either the c.v. is 0.30 with no bias, or bias in ageing is introduced (Figure 3 and Figure 4). Fishing pressure is a more important driver than auto-correlation in recruitment variation, of the total error and bias: the model runs with the higher fishing pressure scenarios (R2-R4) had greater error and bias than those with lower fishing pressure (R1-R3).

An ageing bias of one is approximately equivalent, by the RMSETOT criterion, to a c.v. of 0.30 in ageing error without bias (Figure 3).

With an ageing bias of two, the RMSETOT is approximately double that for model runs with no bias in ageing and an ageing error c.v. of 0.10 (Figure 5 and Figure 6). Bias contributes 25–35% to the RMSETOT, and is about double that for scenarios with an ageing bias of one.

With no ageing bias and ageing error variation, RMSETOT decreases with the sample sizes taken for direct ageing (Figure 7 and Figure 8). Otherwise, due to the domination of RMSETOT by the error contribution from ageing bias and ageing error variation, there is little difference with different sample sizes.

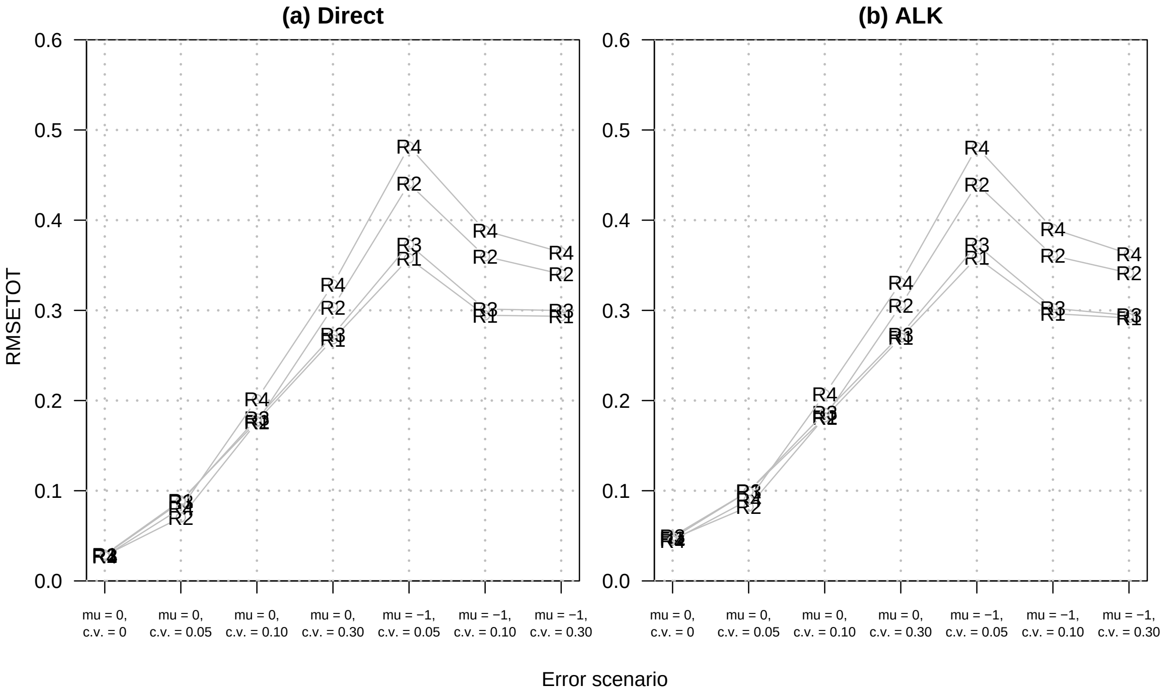

Figure 3: Total mean error (RMSETOT) for the four model scenario. The number of otolith sampled per landing for direct ageing is 50. The x-axis shows the ageing error mean and c.v..

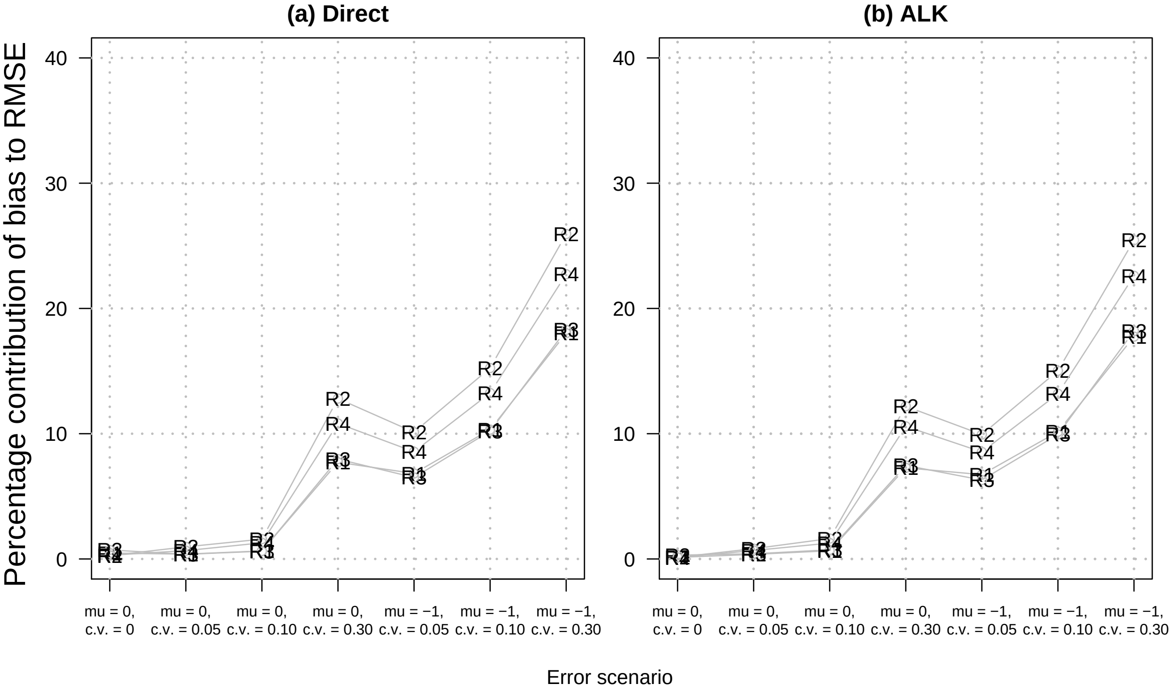

Figure 4: Percentage contribution of the bias for the four model scenarios with a bias in ageing of one. The number of otoliths sampled per landings is 50. The x-axis shows the ageing error mean and c.v..

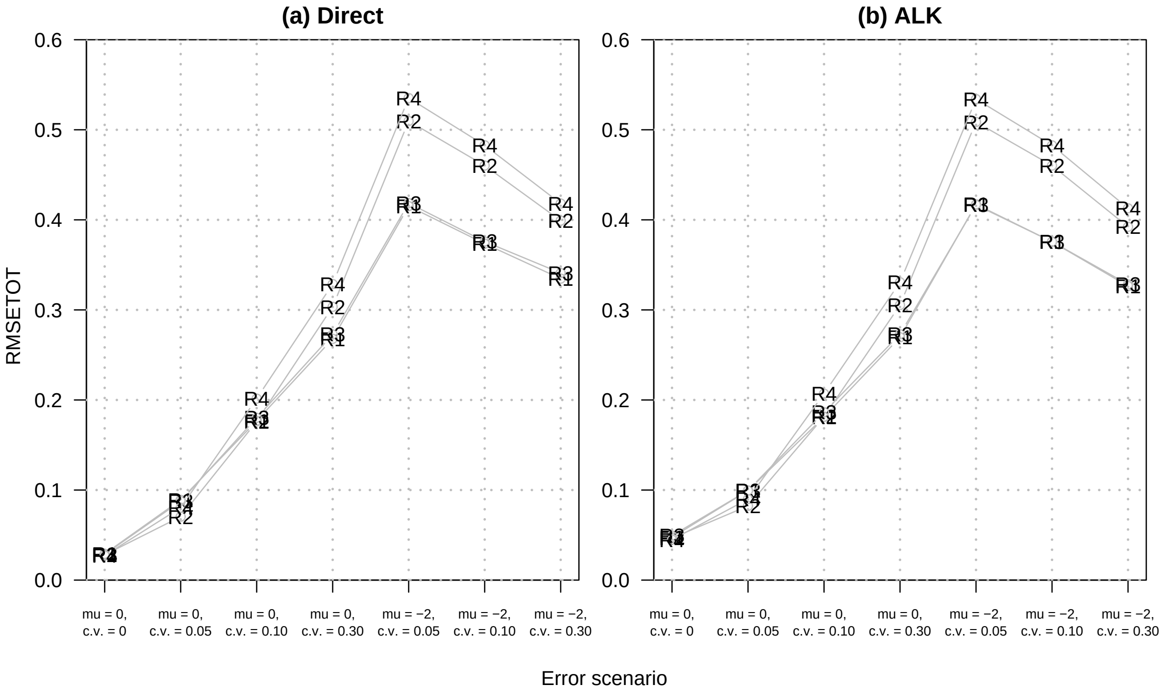

Figure 5: Total mean error (RMSETOT) for the four model scenario with a bias in ageing of two. The number of otolith sampled for direct ageing is 50 per landing. The x-axis shows the ageing error mean and c.v..

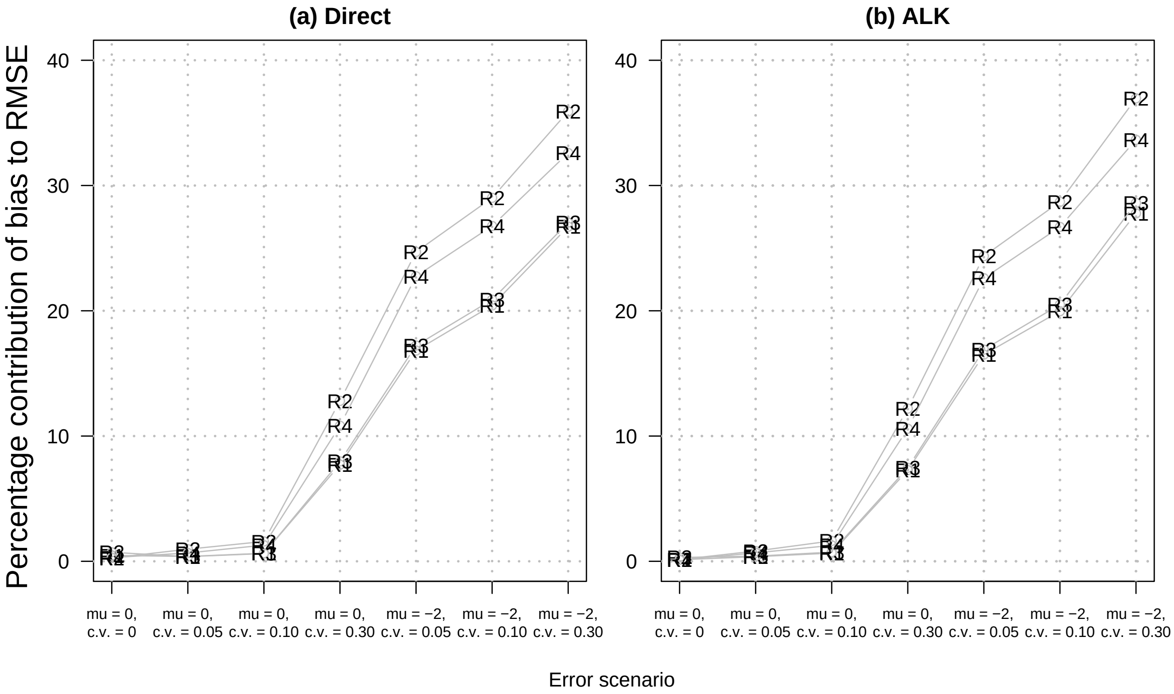

Figure 6: Percentage contribution of the bias for the four model scenarios with a bias in ageing of two. The number of otoliths sampled for direct ageing is 50 per landing. The x-axis shows the ageing error mean and c.v..

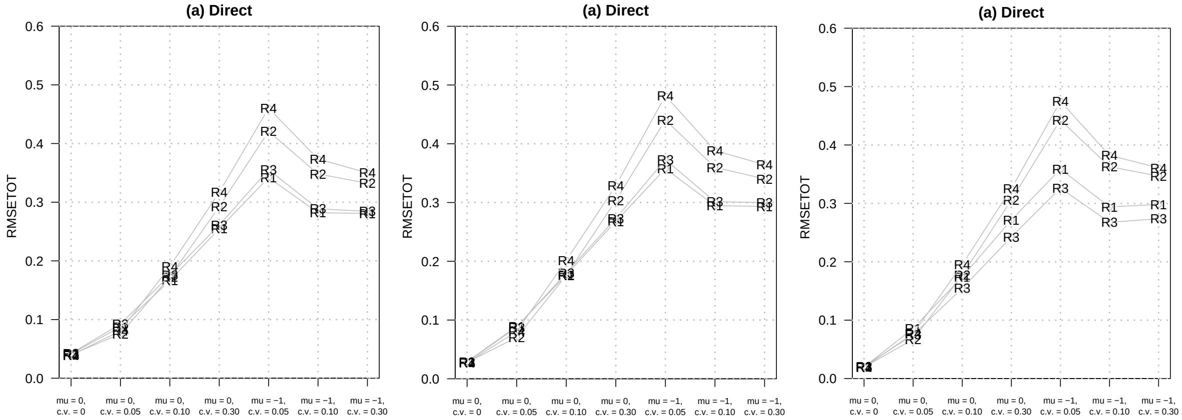

Figure 7: Direct sampling. Total mean error (RMSETOT) and variation by number of otoliths sampled per landing: 25 per landing (left), 50 per landing (middle), 100 per landing (right). The x-axis shows the ageing error mean and c.v..

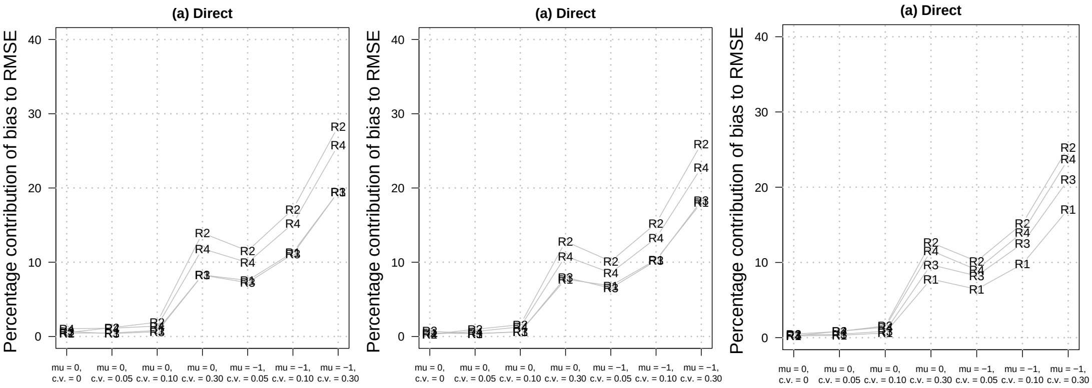

Figure 8: Direct sampling. Percentage contribution of the bias variation by number of otoliths sampled per landing: 25 per landing (left), 50 per landing (middle), 100 per landing (right). The x-axis shows the ageing error mean and c.v..

7. DISCUSSION

There is very little difference between simulation results using the age-length-key and direct ageing approaches, which is to be expected given that the model has a single step for the year with no growth within it. However, as the sub-sampling scheme for otoliths is different for the two approaches across the ages, the total error by age may have some differences.

For the direct ageing approach there was little difference between model runs in which the number of otoliths per landing was halved or doubled from the default of 50. With 25 landings per year, and 25 otoliths sampled per landing, a total of 625 otoliths are sampled per year. This is a relatively high number of otoliths and typically in catch-at-age studies taking more than this gives little further reduction in catch-at-age error, particularly under the model simplification here where there is no variation in the length distributions between landings (including variation would increase the error for smaller samples).

As is to be expected the error increases with both ageing error bias and variation. For a given ageing error bias and variation, the catch-at-age error is greater for higher fishing pressures. At higher fishing pressures the population is fished down more, meaning that the population is dominated by younger fish. As the ageing bias is added in an absolute sense, and so affects the younger aged fish more, then this result is expected.

For inexperienced readers, blue mackerel ageing can be out by 1-2 years compared to experienced readers, and the simulation study indicates that this would be equivalent to introducing a c.v. of at least 0.30. However, under the revised ageing protocol for blue mackerel bias appears to be less of a problem for all readers, so the introduced additional c.v.s would be far less (Manning & Marriot 2011). For EMA 1, due to the large inter-annual variability in age structure samples taken from the mostly purse-seine fishery, no further sampling is currently proposed. A new trawl survey for EMA 7 is currently proposed, for which otolith sampling will take place.

8. CONCLUSION

From the model simulations, the main contributions to the error in estimated catch-at-age are the ageing error bias and variability, increasing with both of these. For a given ageing error and bias the error increases with the fishing pressure. Under the range of scenarios considered here, the catch-at-age method and number of otoliths taken per landing make little contribution to the error.

Inexperienced blue mackerel readers can be out by 1–2 years compared to experienced readers. The model simulations suggest that this will result in an error approximately equivalent to a c.v. of at least 0.30 (with no ageing bias). However, under the revised protocol for ageing, bias is likely to be far less of a problem for all readers.

9. ACKNOWLEDGEMENTS

Thank you to Michael Manning for the use of his code, and to Ian Doonan for reviewing the manuscript. This work was funded under the MFish project EMA200502.

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