# Chapter 8

# A gender-disaggregated assessment of the South African hake resource, fitting directly to age-length keys: a New Reference Case

## Summary

The assessment methodology for the hake resource is refined to include gender-disaggregation, and to fit directly to age data and estimate growth curve parameters internally in the likelihood maximisation process. This approach successfully resolves the conflict between fits to catch-at-age and catch-at-length distributions evident in earlier assessments. The current *M. paradoxus* female spawning biomass is estimated to be at 59% of its MSY level, whereas the corresponding *M. capensis* estimate is well above that level.

## 8.1 Introduction

In updating the assessment presented in Chapter 4, the first step has been to incorporate catch-at-length information directly when fitting the population model. Indeed, it was discovered that in years for which age-length keys were not available, catches-at-length had been converted to catches-at-age based on averages of age-length keys for other years (a problematic and potentially biased approach). This work resulted in the development of a "New Baseline" assessment in 2008, in which catch-at-length information was used directly in years for which ALK are not available (Rademeyer and Butterworth 2008). However, the "New Baseline" fits to the commercial and survey catches-at-age and catches-at-length data were poor (Figures 8.1 and 8.2), the likely reason for this being a conflict between the catch-at-age and catch-at-length information. For example, for the offshore trawl fleet (West Coast and both coasts), the observed length distribution of the catch is very narrow compared to a relatively wide range of ages observed in the catches-at-age (Figure 8.1).

The Review Panel at the December 2008 International Stock Assessment Workshop (Punt and Smith 2008) made the following recommendation with respect to assessment of the hake resource "A sex-structured population dynamics model should be fit to the conditional age-at-length data (age-length keys) and length-frequency data (by sex when such data are available). The growth curves (and the variation in length-at-age) should be estimated within the assessment." The recommendation arose in large part from the need to resolve this conflict between catch-at-age and catch-at-length data, and growth curves input to the then current 2008 "New Baseline" assessment (Rademeyer and Butterworth 2008).

The reason for the gender-disaggregation is that very clear gender-specific differences in somatic growth exist for both *M. paradoxus* and *M. capensis* (Payne 1989), in fact more so than between species (as evidenced by the growth curve fits discussed below). Routine application of age-length keys to obtain catch-at-age proportions had been conducted without attention to gender-specific differences, but gender-differential growth means that larger sized males are not well represented in the catch. This could confound estimates based on catch-at-age data developed from a gender-aggregated age-length key, which might consequently under-represent the number of older hake present. This in turn could affect estimates of natural mortality as well as distort estimates of year-class strength. The comparatively low variability of previous estimates of the recruitment has been a puzzle and concern, which might be resolved by gender differentiation of the assessments. Furthermore there is a sex-imbalance in certain components of the fishery: for example Geromont *et al.* (1995) estimated a female proportion in the South Coast longline catches as high as 83%.

In the light of these considerations, the assessment of the hake resource was refined to incorporate gender- as well as species-differentiation. Thus in this analysis, the genders are modelled separately. As recommended above, the model is also fit directly to age-length keys (ALKs) and length frequencies (as e.g. in Punt *et al.* 2006, Taylor *et al.* 2005), rather than to the age frequency information which multiplying the two would provide. There are three reasons for this:

a) ALKs are not available for all years and surveys or fisheries, so that length distribution data have to be fitted directly in those cases.

b) The fishery selectivity is essentially length- rather than age-specific; the assumption of age-specific selectivities when fitting to age-distribution data will lead to misfitting of length distribution data in these circumstances (e.g. the lower tails of the length distributions of younger fish are not present in catches, but an age-specific selectivity requires them to be).

c) The feature of the data described in b) leads to a bias in the estimation of hake growth curves if estimated directly from hake age data, leading to the lengths at younger ages being positively biased; growth curve parameters need to be estimated internally within the assessment to correct for this bias.

This Chapter reports the results from this refined assessment, which is termed the "new Reference Case" (RC). This assessment forms the basis from which the Operating Models that provide the basis for simulation testing of the revised OMP (OMP-2011) for hake are developed (Chapter 9).

## 8.2 Data and Methods

Appendix 8.I details the data used in this analysis, while the specifications and equations of the overall model are set out in Appendix 8.II.

## 8.3 Results and Discussion

Values of components of the negative log likelihood and estimates of management quantities for the new Reference Case are given in Table 8.1, while Figure 8.3 plots the spawning biomass trajectories. The spawning biomass trajectories for *M. paradoxus* and *M.*

*capensis* show little gender difference, with the current 2010 depletion estimated to be at 15% and 54% for *M. paradoxus* and *M. capensis* respectively. For *M. capensis* the female spawning biomass is estimated to be 12% above its MSY level, whereas the corresponding component of the *M. paradoxus* population is estimated at 59% of that level.

The estimated commercial and survey selectivities are shown in Figures 8.4 and 8.5 respectively. Apart for *M. paradoxus* on the South Coast, the male and female selectivities at length are assumed to be the same and are then converted to gender-specific selectivities at age. Because of selectivity differences between males and females apparent in the South Coast surveys for *M. paradoxus*, gender-specific selectivities are estimated for this species in the South Coast autumn and spring surveys, with the female selectivities (for *M. paradoxus* only) scaled downwards for these two surveys by a common factor across lengths which is estimated in the model fitting procedure. This gender difference is assumed to affect the commercial fleet as well, and the female selectivity for the South Coast offshore trawl fleet (the only fleet assumed to catch *M. paradoxus* on the South Coast) is therefore also scaled downwards by a factor estimated in the model fitting. The female selectivity scaling factors estimated for the South Coast spring and autumn surveys and the offshore trawl fleet are 0.13, 0.27 and 0.10 respectively.

All the commercial selectivities show a decrease for large fish. This decrease is estimated for all fleets apart from the offshore trawl and South Coast handline fleets for *M. capensis*. For the *M. capensis* offshore trawl fleet, the selectivity slope is fixed to 1/3 of the inshore trawl fleet slope estimated, while for the handline fleet, the selectivity slope is taken as the average of the estimated longline and inshore fleet slopes.

A penalty has been added to the -lnL to constrain the survey *q*'s for each species not to exceed 1 (see equation App.8.II.34). This amounts to the assumption that there is no substantial herding effect which is biasing the swept-area estimates of biomass from these trawl surveys, and precludes survey biomass estimates from (on average) exceeding the underlying available biomass. Huse *et al.* (2001) estimated a swept area survey *q* of about 0.8 for Namibian hake by comparing acoustic and swept area data. For the Reference Case, the *M. paradoxus q* for the West Coast summer survey hits the upper boundary of 1 (see Table 8.1).

Figure 8.6 plots the gender-specific growth curves estimated in the model, as well as the estimated length-at-age distributions. The difference between male and female growth curves is estimated to be more important for *M. paradoxus* than for *M. capensis*. *M. capensis* is estimated to grow larger than *M. paradoxus*.

Figure 8.7 plots the estimated stock-recruitment relationships, and the time series of residuals about these relationships for both species. Note that compared to the 2006 OMs which used Beverton-Holt relationships, these more recent OMs used a more general form which can take on a Ricker-like behaviour (see equation App.8.II.4b). A penalty was added to the -lnL so that the mean of the estimated recruitment residuals is close to zero (see equation App.8.II.43). The reason for this is that fits to the last 30 years for which these residuals could be estimated generally showed averages appreciably below zero for *M. capensis*. If such fits had been taken through to projections, this would have meant that immediate future recruitment for *M. capensis* would have been higher on average than over recent years, thus giving a likely spuriously positive impression of resource production. It was felt more appropriate to force this average level of future production to be similar to that over the past three decades. While the possibility that those decades constitute a regime of generally low *M. capensis* productivity cannot be excluded, the associated effective changes in *K* are considered better reserved for consideration in robustness tests. The extent of residual variability indicated for Figure 8.7 remains low compared to the norm for populations of similar demersal species (Ricard *et al.* 2011) (the output $\sigma_R$ values are 0.26 and 0.29 for *M. paradoxus* and *M. capensis* respectively).

Figures 8.8 and 8.9 show the fits to the CPUE and survey biomass series. The fits are reasonable for all series, especially when balanced against each other, but there are indications of positive correlation in residuals over time which means that estimates of variance based on likelihood profiles would be negatively biased.

The fits to the commercial catch-at-length data are shown in Figure 8.10. The length-at-age distributions are assumed to follow a log-normal distribution rather than a normal distribution, as plots of these data are indicative of skew distributions (see Figures App.8.I.2-4). The fits are averaged over all the years for which data are available and are reasonable for all the data sets. There are however some patterns evident in the bubble plots of residuals which could perhaps be improved by having further periods between which selectivities change.

The fits to the survey gender-aggregated and gender-disaggregated catch-at-age data are shown in Figures 8.11 and 8.12 respectively. These fits are also broadly reasonable. In particular, the problem of the lack of fit evident in the corresponding plots for the 2008 "New Baseline" assessment (Rademeyer and Butterworth 2008) appears to be resolved.

The fit to the ALKs is shown in Figure 8.13. The observed and predicted ALKs are compared aggregated over all ALKs, first summed over ages, which should be exactly equal by construction and then summed over lengths. The ALK likelihood downweighting factor, $w$, (see equation App.8.II.41) was set to 0.01 as fits from earlier runs with $w$=0.001 indicated an apparent lack of influence (underweighting) of these data.

The maturity-at-age ogive used in the new Reference Case is shown in Figure 8.14. Since resource depletion estimates can be sensitive to the manner in which spawning biomass is defined, Table 8.2 compares the estimated 2009 depletions for this ogive with those for fish of age 3+ and of age 4+ (definitions used for earlier assessments). Results for the ogive lie between those for fish of age 3+ and of age 4+.

Table 8.1: Values of components of the negative log likelihood and estimates of management quantities for the Reference Case. The modified Ricker $\gamma$ values are given in parentheses next to the *h* values. The survey slopes given are for the West Coast summer and South Coast autumn surveys respectively (the two longest series). Note: MSY and related quantities have been calculated assuming a fishing pattern that is the average over the last five years (2005-2009). The natural mortality values shown in bold are fixed.

| | | | | |
|---|---|---|---|---|
| | -lnL total | -94.5 | | |
| | CPUE historic | -36.9 | | |
| | CPUE GLM | -136.4 | | |
| | Survey | -33.9 | | |
| | Commercial CAL | -51.3 | | |
| | Survey CAL (sex-aggr.) | -6.6 | | |
| | Survey CAL (sex-disaggr.) | 20.4 | | |
| | ALK | 124.4 | | |
| | Recruitment penalty | 9.1 | | |
| | Selectivity smoothing penalty | 16.2 | | |
| | | Both | Males | Females |
| *M. paradoxus* | $K^{sp}$ | 1363 | 649 | 715 |
| | $h$ | 1.08 | (0.18) | |
| | $B^{sp}_{2009}$ | 208 | 107 | 102 |
| | $B^{sp}_{2009}/K^{sp}$ | 0.15 | 0.16 | 0.14 |
| | $B^{sp}_{MSY}$ | | | 174 |
| | $B^{sp}_{MSY}/K^{sp}$ | | | 0.24 |
| | $B^{sp}_{2009}/B^{sp}_{MSY}$ | | | 0.59 |
| | $MSY$ | 113 | | |
| | $M_{2-}$ | **0.75** | | |
| | $M_{5+}$ | **0.375** | | |
| | survey slopes (cm$^{-1}$) | 0.002 | 0.141 | |
| *M. capensis* | $K^{sp}$ | 516 | 254 | 262 |
| | $h$ | 1.01 | (1.58) | |
| | $B^{sp}_{2009}$ | 279 | 142 | 137 |
| | $B^{sp}_{2009}/K^{sp}$ | 0.54 | 0.56 | 0.52 |
| | $B^{sp}_{MSY}$ | | | 122 |
| | $B^{sp}_{MSY}/K^{sp}$ | | | 0.47 |
| | $B^{sp}_{2009}/B^{sp}_{MSY}$ | | | 1.12 |
| | $MSY$ | 69 | | |
| | $M_{2-}$ | **0.75** | | |
| | $M_{5+}$ | **0.375** | | |
| | survey slopes (cm$^{-1}$) | 0.008 | 0.071 | |
| 2009 species ratio $B^{sp}$ | | 1.34 | 1.33 | 1.34 |

| | Both | *paradoxus* | *capensis* |
|---|---|---|---|
| Survey q's: | | | |
| WC summer | | 1.00 | 0.39 |
| WC winter | | 0.96 | 0.53 |
| SC spring | | 0.37 | 0.67 |
| SC autumn | | 0.40 | 0.82 |
| Additional variance: | | 0.15 | 0.11 |
| survey CAL 0's: | | | |
| Sex-aggr. data: | | | |
| WC summer | | 0.08 | 0.14 |
| WC winter | | 0.08 | 0.13 |
| SC spring | | 0.13 | 0.06 |
| SC autumn | | 0.11 | 0.04 |
| Sex-disaggr. data: | | | |
| WC summer | | 0.07 | 0.11 |
| WC winter | | - | - |
| SC spring | | 0.07 | 0.05 |
| SC autumn | | 0.09 | 0.05 |
| CPUE 0's: | | | |
| WC ICSEAF | 0.25 | | |
| SC ICSEAF | 0.25 | | |
| WC GLM | | 0.15 | 0.24 |
| SC GLM | | 0.25 | 0.19 |
| com CAL 0's: | | | |
| WC offshore | 0.07 | | |
| SC offshore | 0.10 | | |
| SC inshore | 0.07 | | |
| WC longline | 0.04 | | |
| SC longline | 0.06 | | |
| offshore | 0.07 | | |

Table 8.2: Estimated 2009 depletion for the new Reference Case spawning biomass, 3+ biomass and 4+ biomass for *M. paradoxus* and *M. capensis*.

| | *M. paradoxus* | *M. capensis* |
|---|---|---|
| $B^{sp}_{2009}/K^{sp}$ | 0.15 | 0.54 |
| $B^{3+}_{2009}/K^{sp}$ | 0.18 | 0.55 |
| $B^{4+}_{2009}/K^{sp}$ | 0.13 | 0.50 |

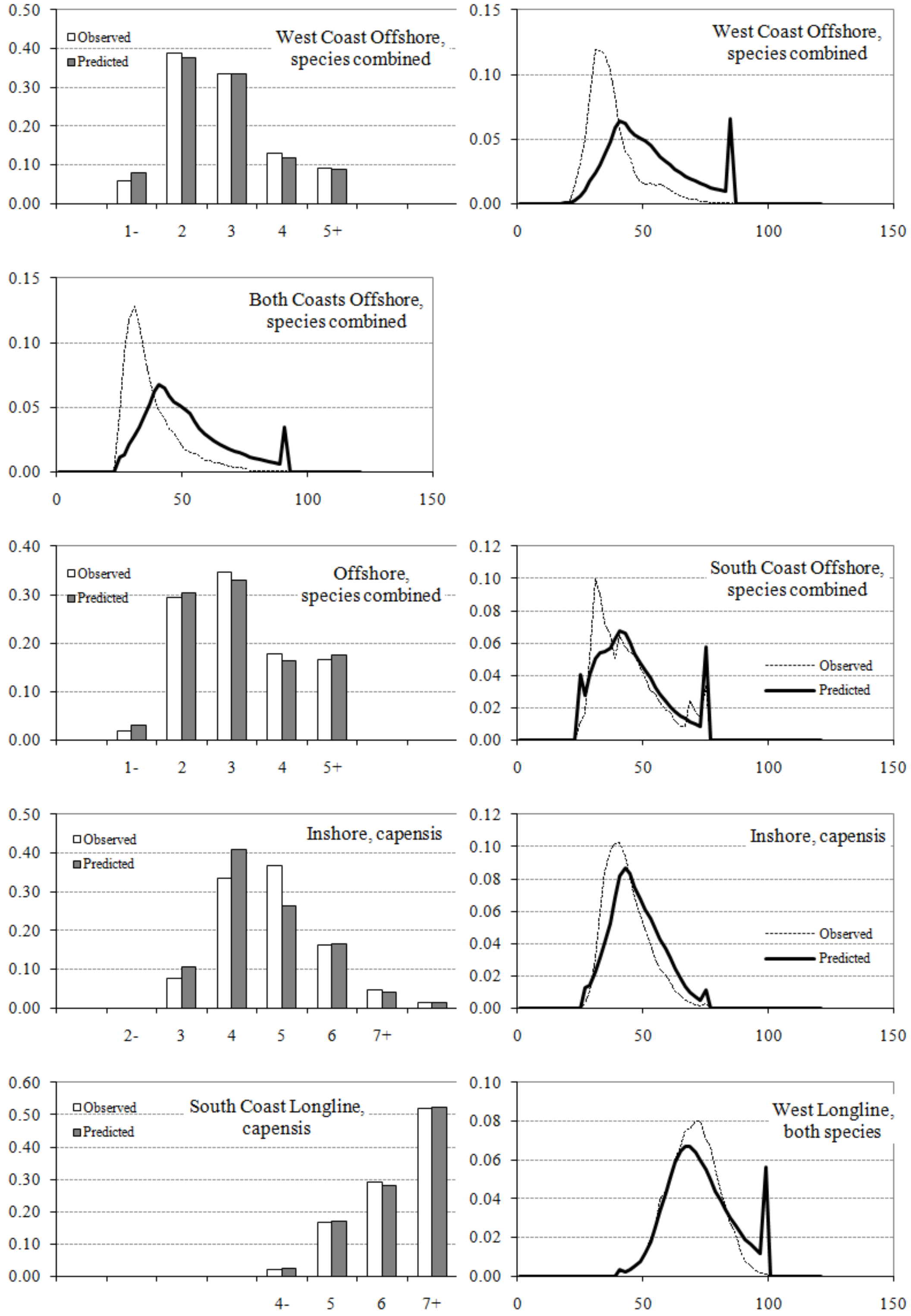
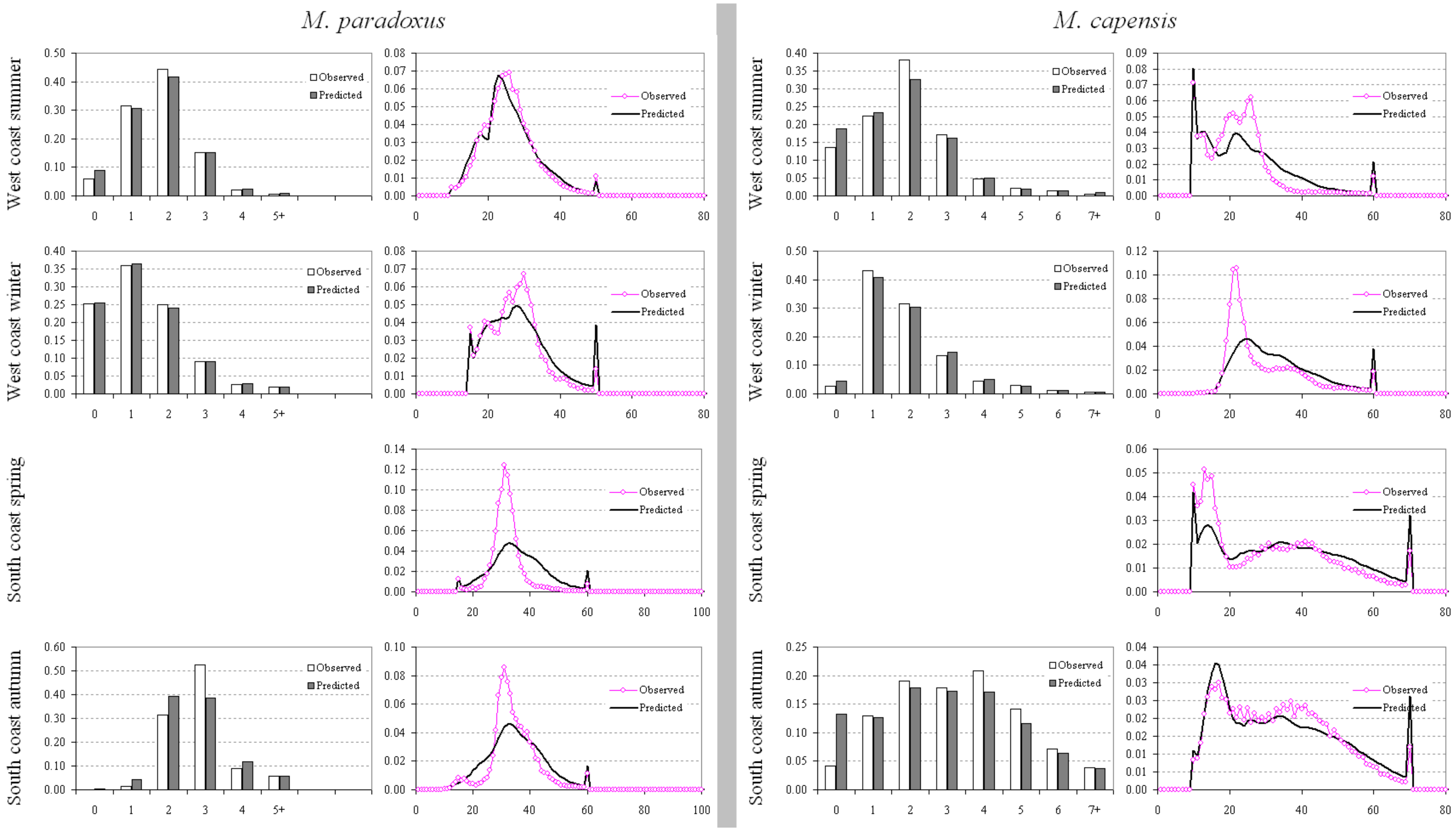


Figure 8.1: Fit to the commercial CAA and CAL data for the "New Baseline" assessment of 2008 (Rademeyer and Butterworth 2008).

Figure 8.2: Fit to survey CAA and CAL for *M. paradoxus* for the "New Baseline" assessment of 2008 (Rademeyer and Butterworth 2008).



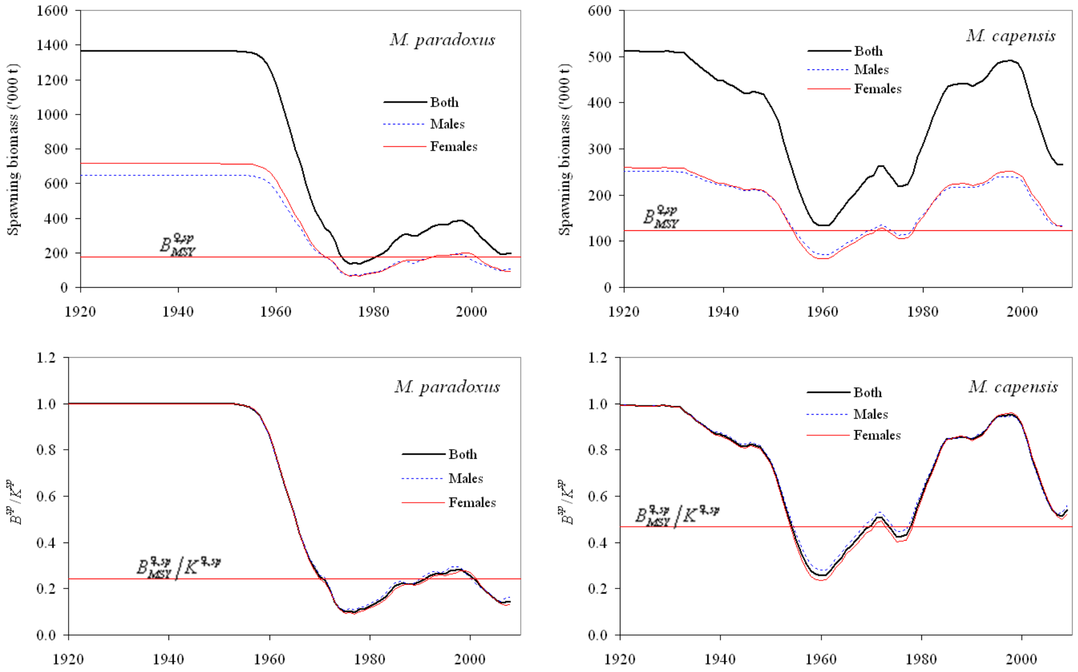


Figure 8.3: Estimated spawning biomass trajectories for *M. paradoxus* and *M. capensis*, both in absolute terms and relative to the pre-exploitation level for the RC.

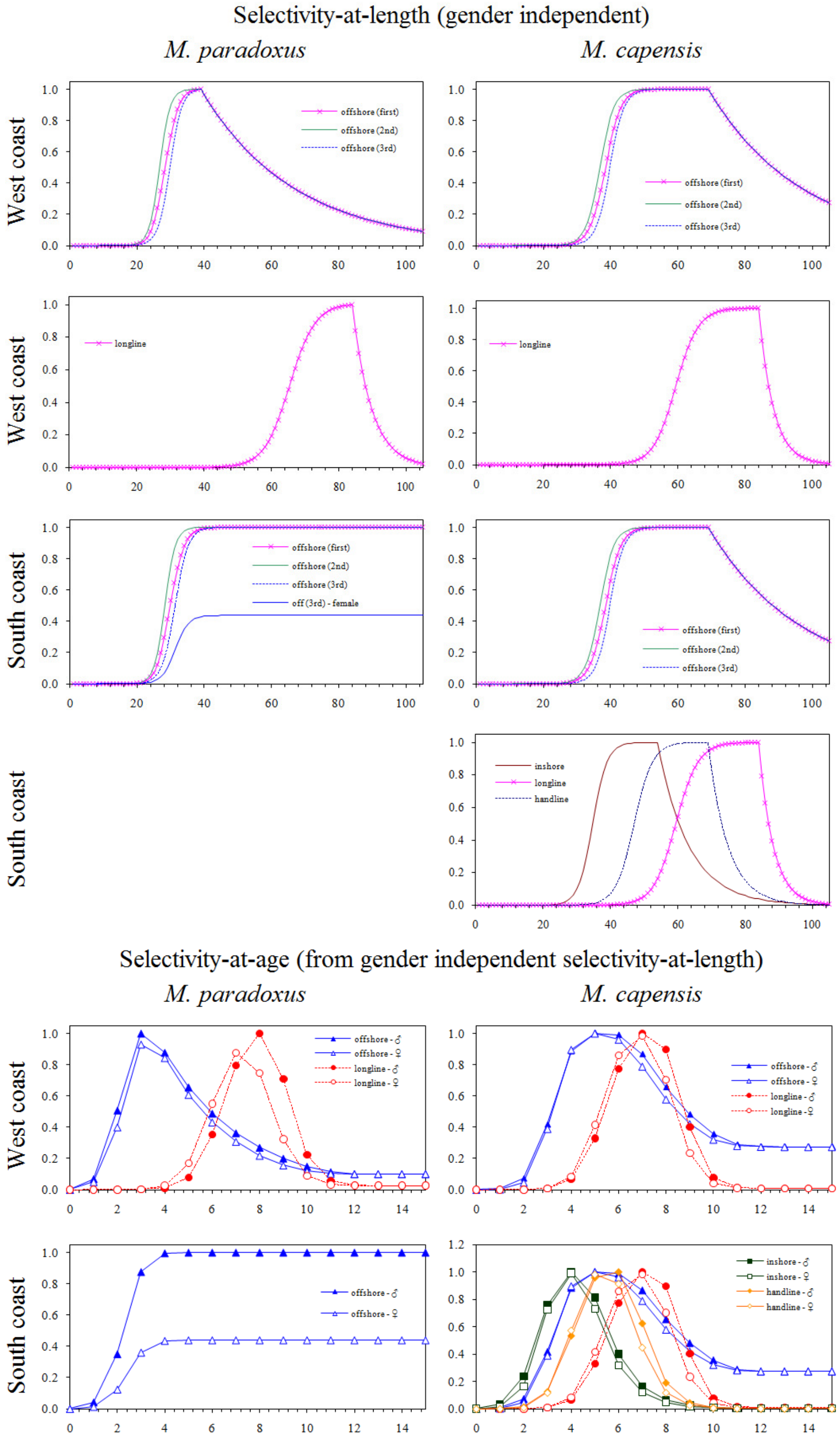
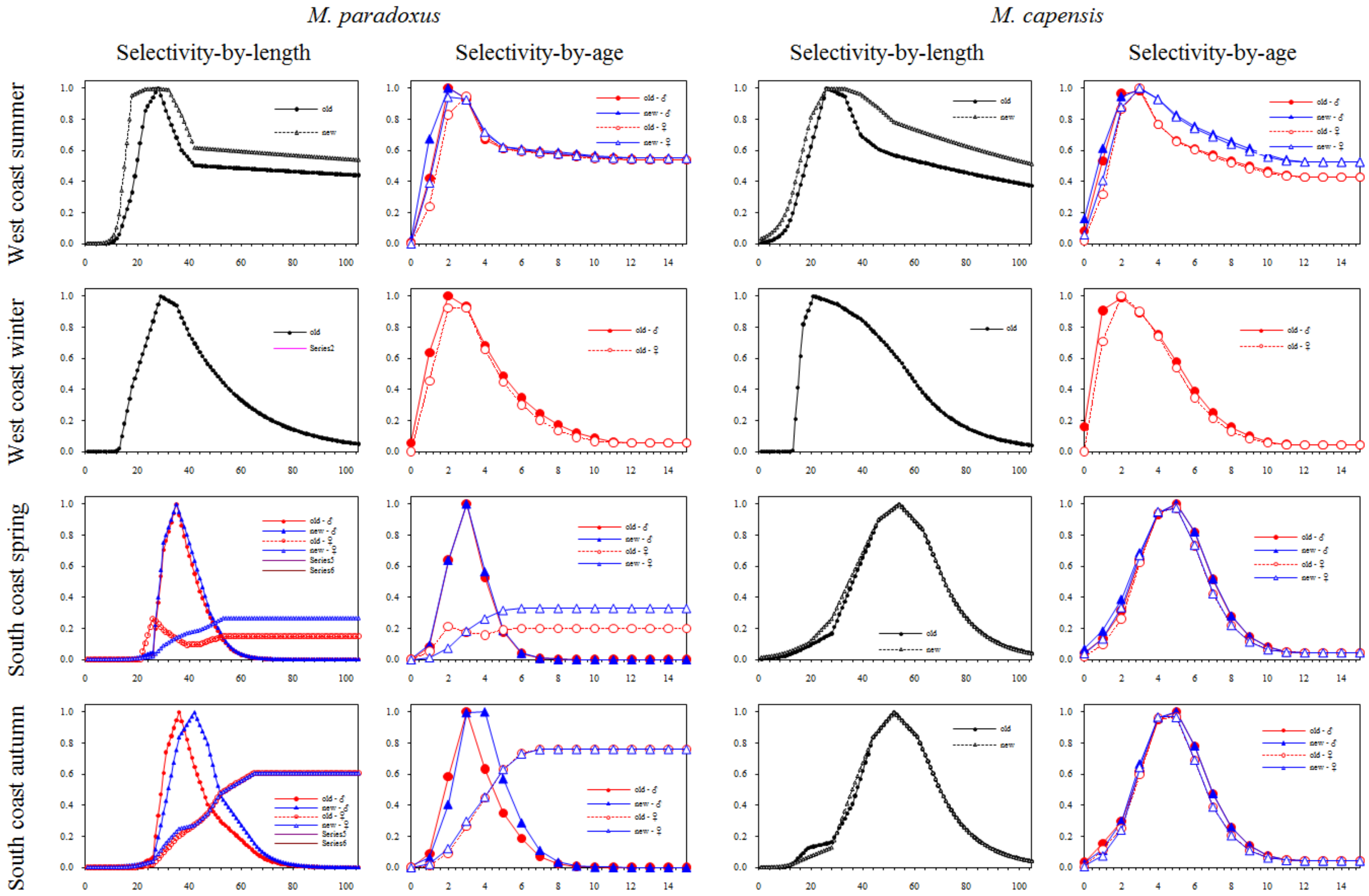


Figure 8.4: Commercial gender-independent selectivities-at-length estimated in the model-fitting and commercial gender-dependent selectivities-at-age that follow from those. Note that because of space constraints, the offshore and longline legends have been omitted for the South Coast *M. capensis* selectivity-at-age plots. The legends for these two fleets are as for those for the West Coast.

Figure 8.5: Survey selectivity-at-length (estimated) for the ‘old’ and ‘new’ *Africana* gear and derived gender-dependent survey selectivity-at-age for each of the four surveys for *M. paradoxus* and *M. capensis*. Note that for the south coast spring and autumn surveys, gender-specific selectivities have been estimated for *M. paradoxus*. For all the other combinations of species and surveys, the selectivities-at-length are gender independent.



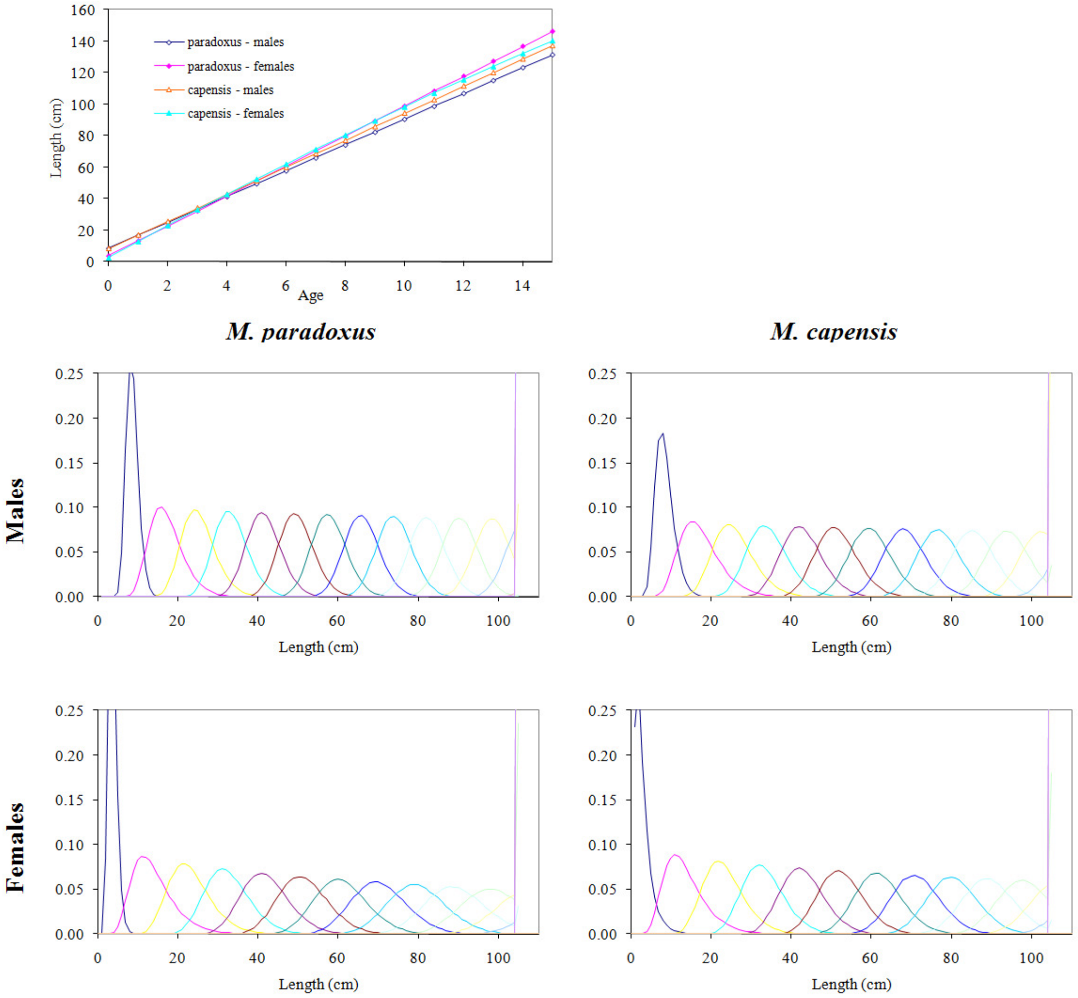


Figure 8.6: Estimated length-at-age relationship and resulting length-at-age distributions for males and females *M. paradoxus* and *M. capensis*. In the lower plots, the distributions, starting from the left, correspond to ages 0, 1, 2, … The 0-year old group has a distribution overlapping zero, which is accumulated into a minus-group of 1 cm length; though such a model for this length distribution is clearly unrealistic, this hardly matters as in implementation the lowest minus-group considered for length is 10 cm, so that any implied structure below that length is ignored.

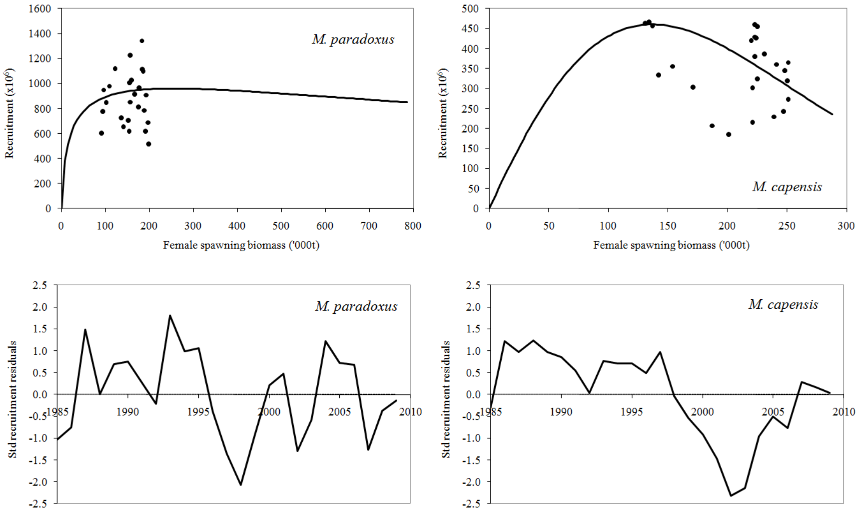


Figure 8.7: Estimated stock-recruitment relationships and time series of standardised stock-recruitment residuals for the RC.

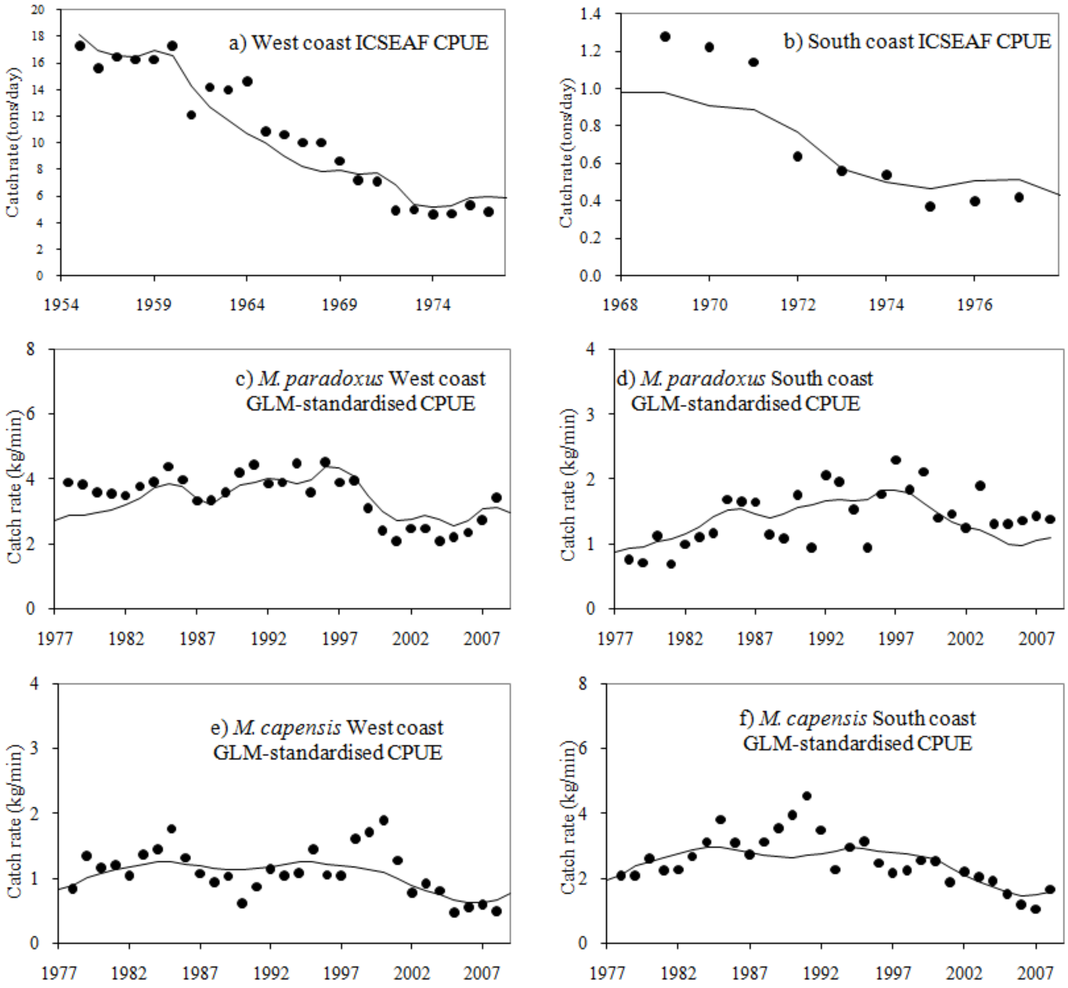


Figure 8.8: Fit of the RC to the CPUE data.

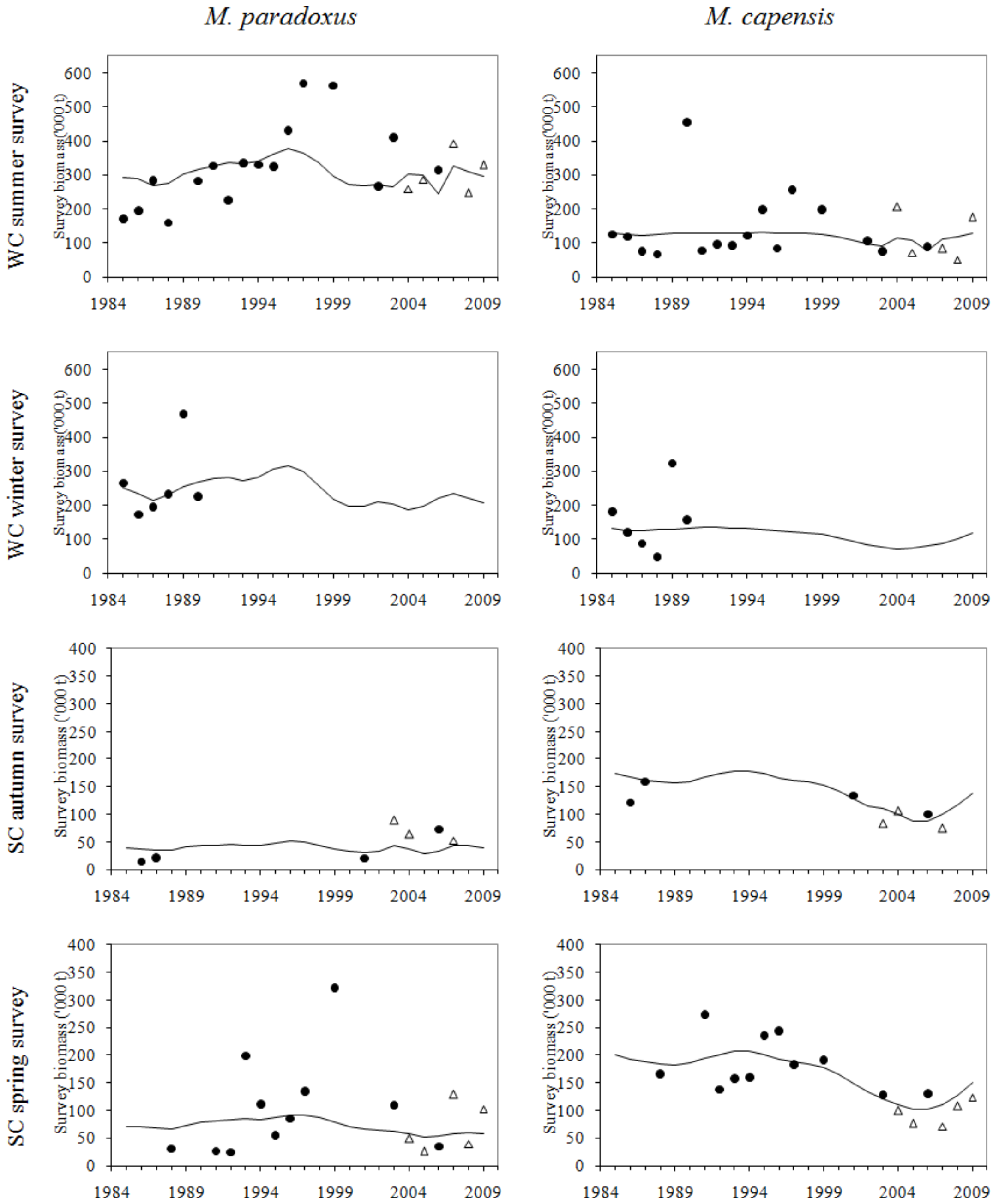


Figure 8.9: Fit of the RC to the survey biomass indices. The triangles represent surveys that have been conducted with the new gear on the *Africana*. These are rescaled by the calibration factor for the species concerned to make them comparable to the other survey results.

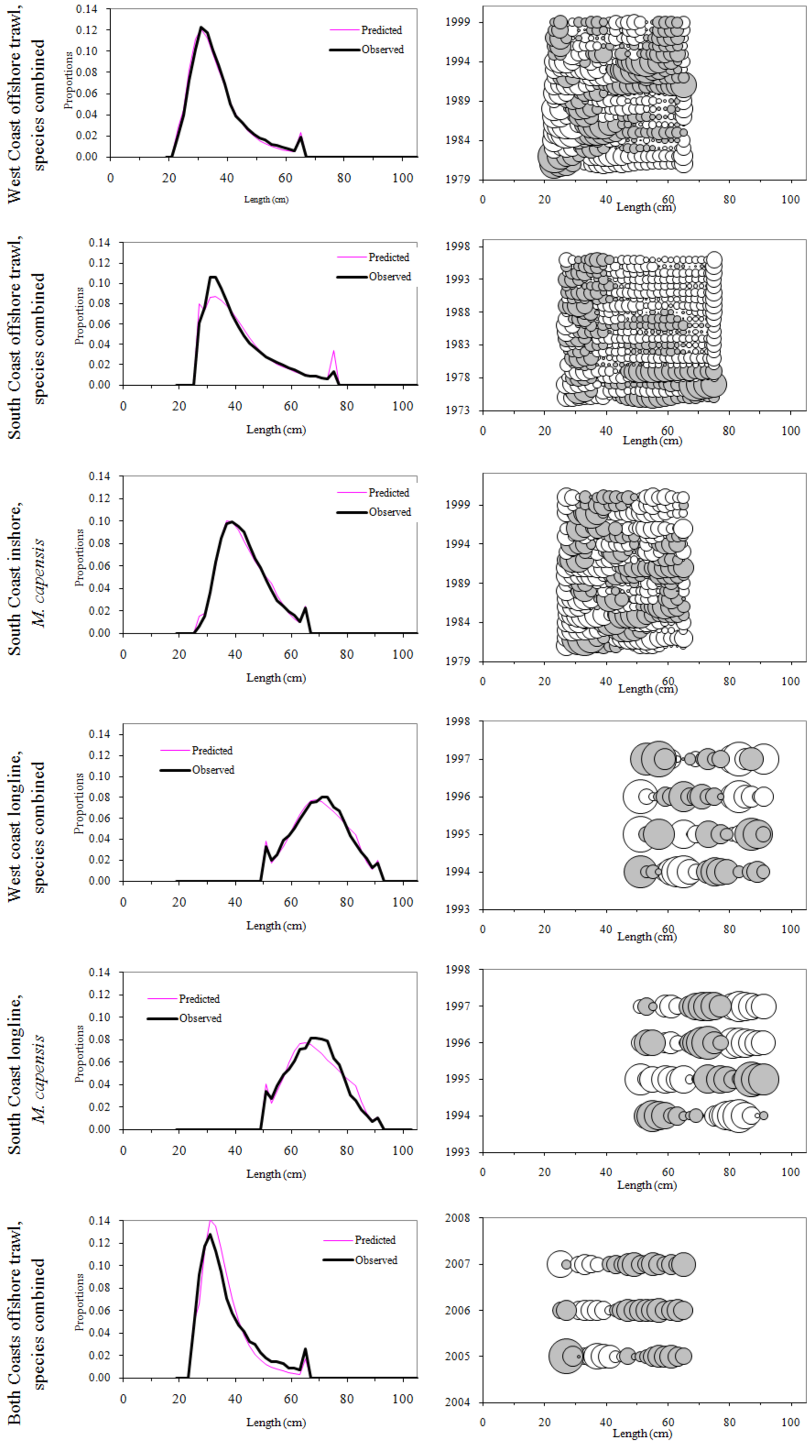


Figure 8.10: Fit of the RC to the commercial proportion-at-length data, aggregated over years for which data are available for the plots on the left. Bubble plots of the corresponding standardised residuals are shown on the right. Here and in the Figures following, the area of the bubble is proportional to the magnitude of the corresponding standardised residuals. For positive residuals the bubbles are grey, whereas for negative residuals the bubbles are white.

Figure 8.11: Fit of the RC to the survey gender-aggregated surveys proportion-at-length data (in some plots, aggregated over years for which data are available).

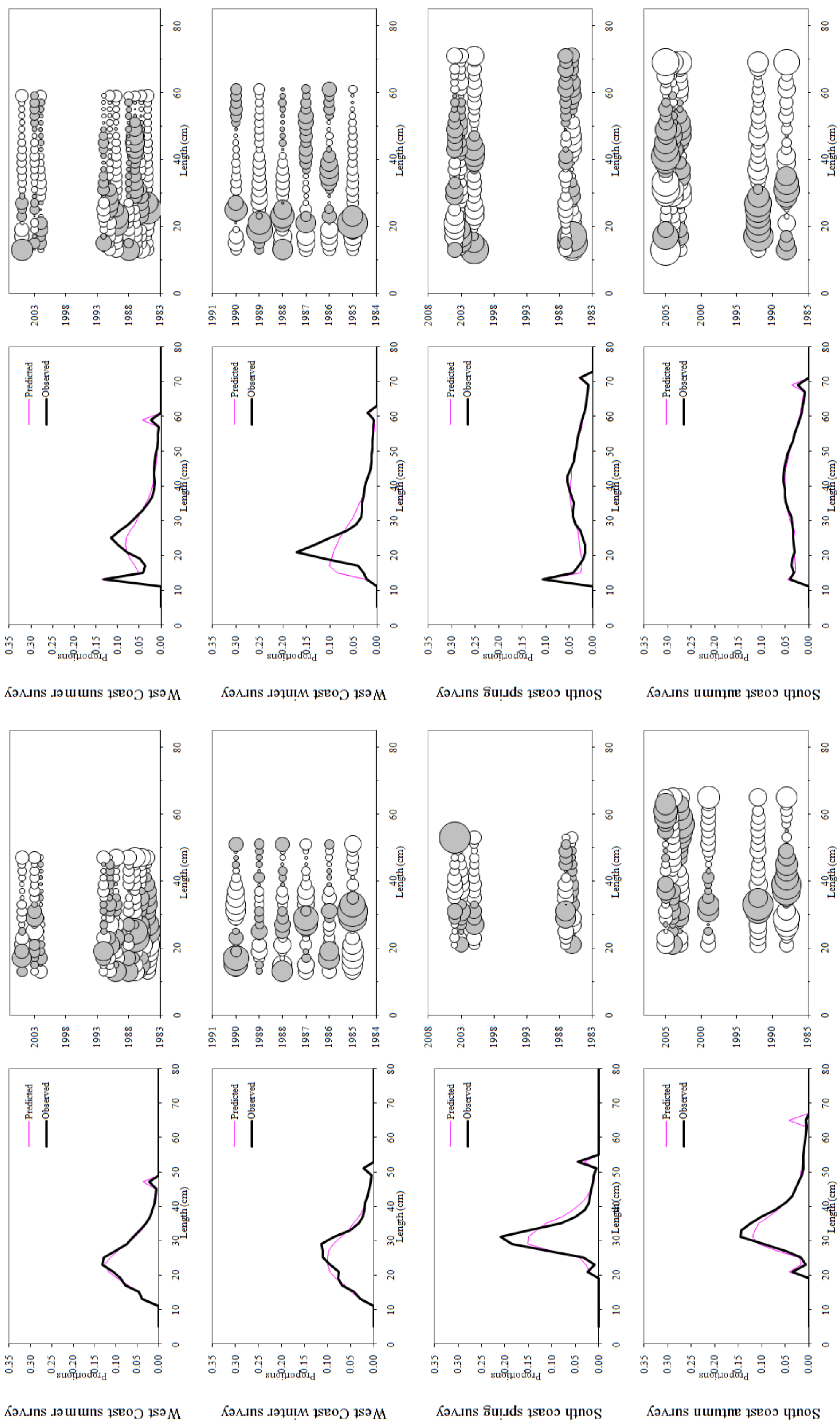


Figure 8.12a: Fit of the RC to the west coast summer survey gender- disaggregated proportion-at-length data (in some plots, aggregated over years for which data are available).

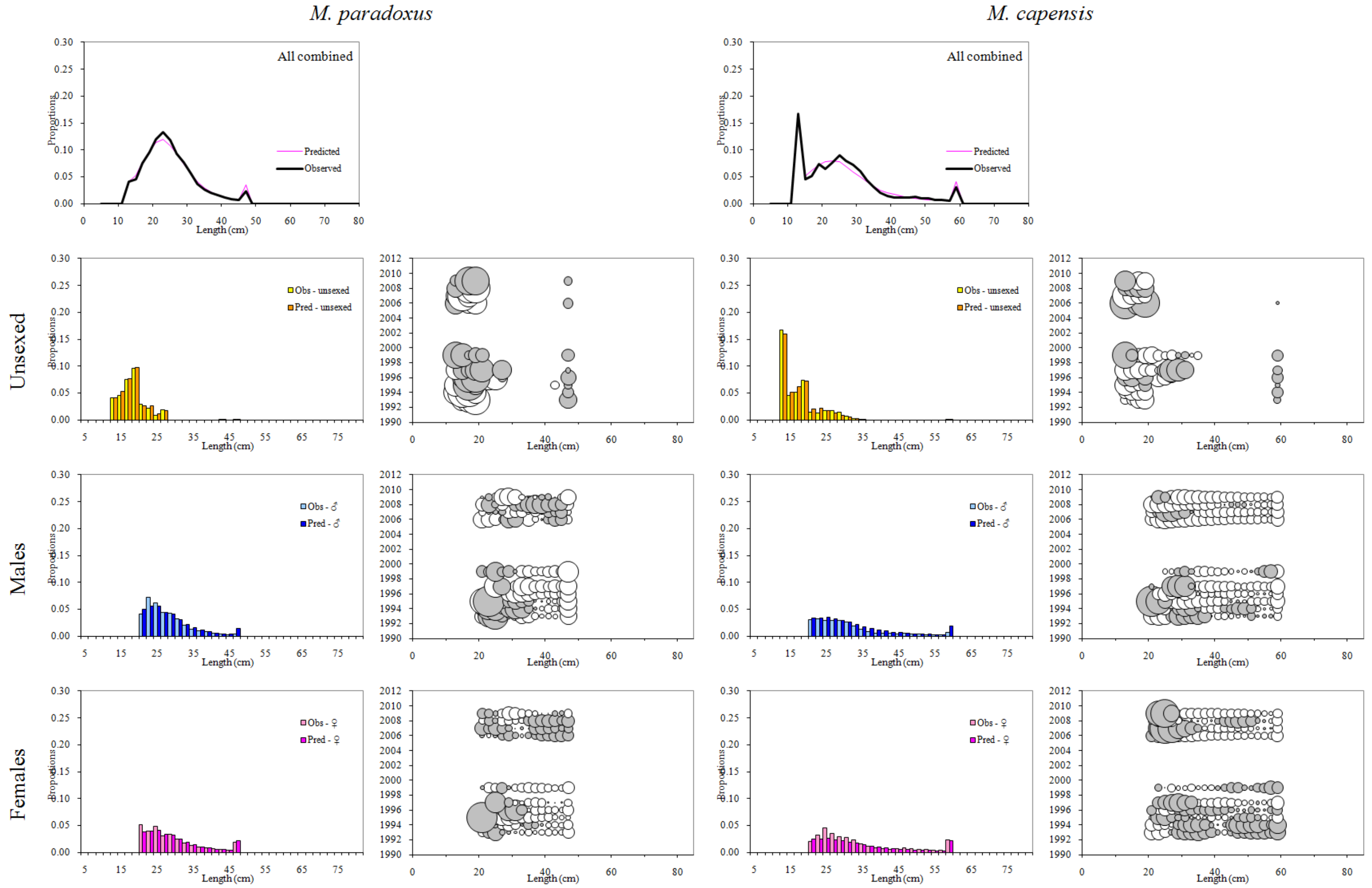


Figure 8.12b: Fit of the RC to the south coast spring survey gender- disaggregated proportion-at-length data (in some plots, aggregated over years for which data are available).

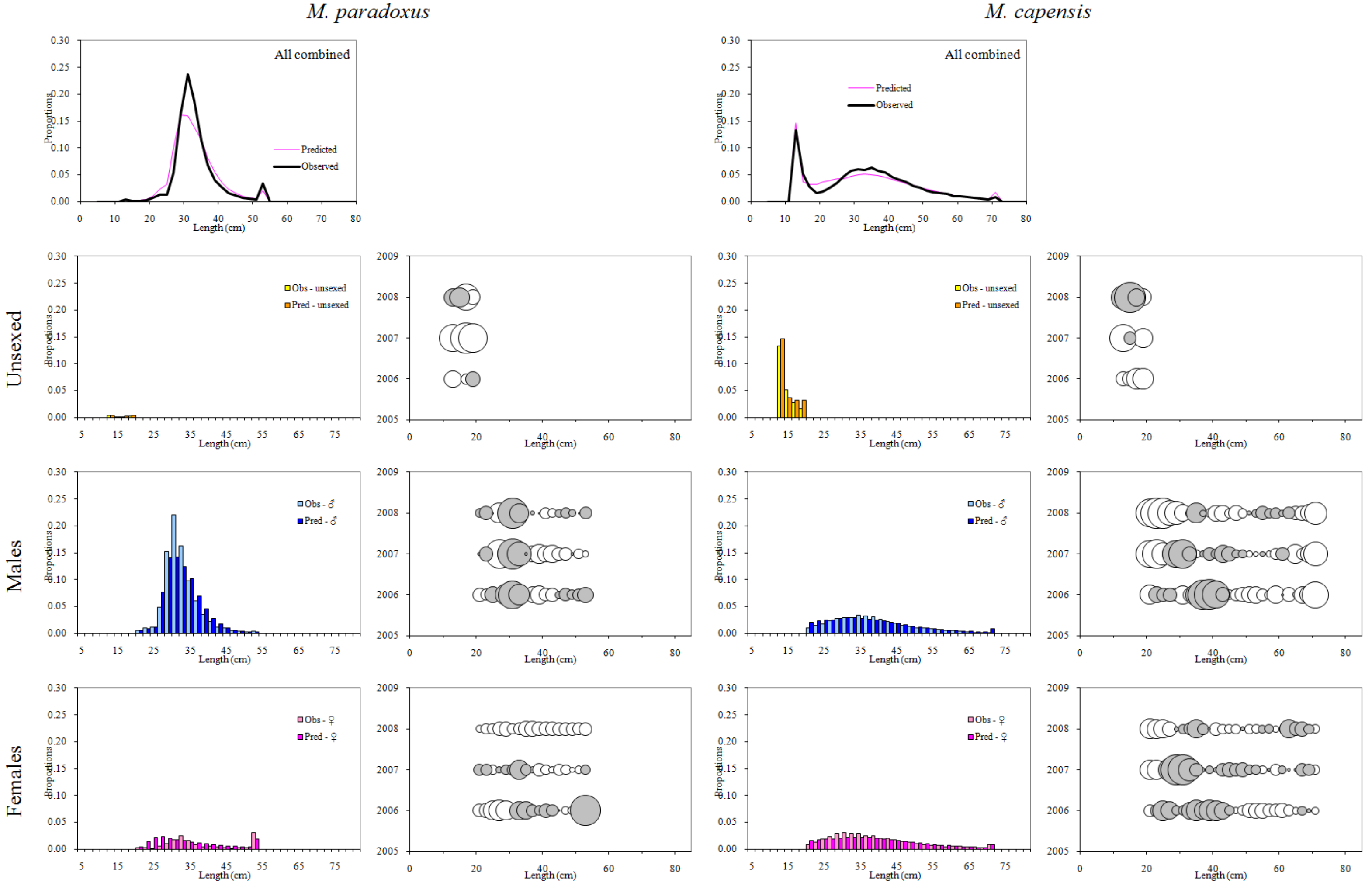


Figure 8.12c: Fit of the RC to the south coast autumn survey gender- disaggregated proportion-at-length data (in some plots, aggregated over years for which data are available).

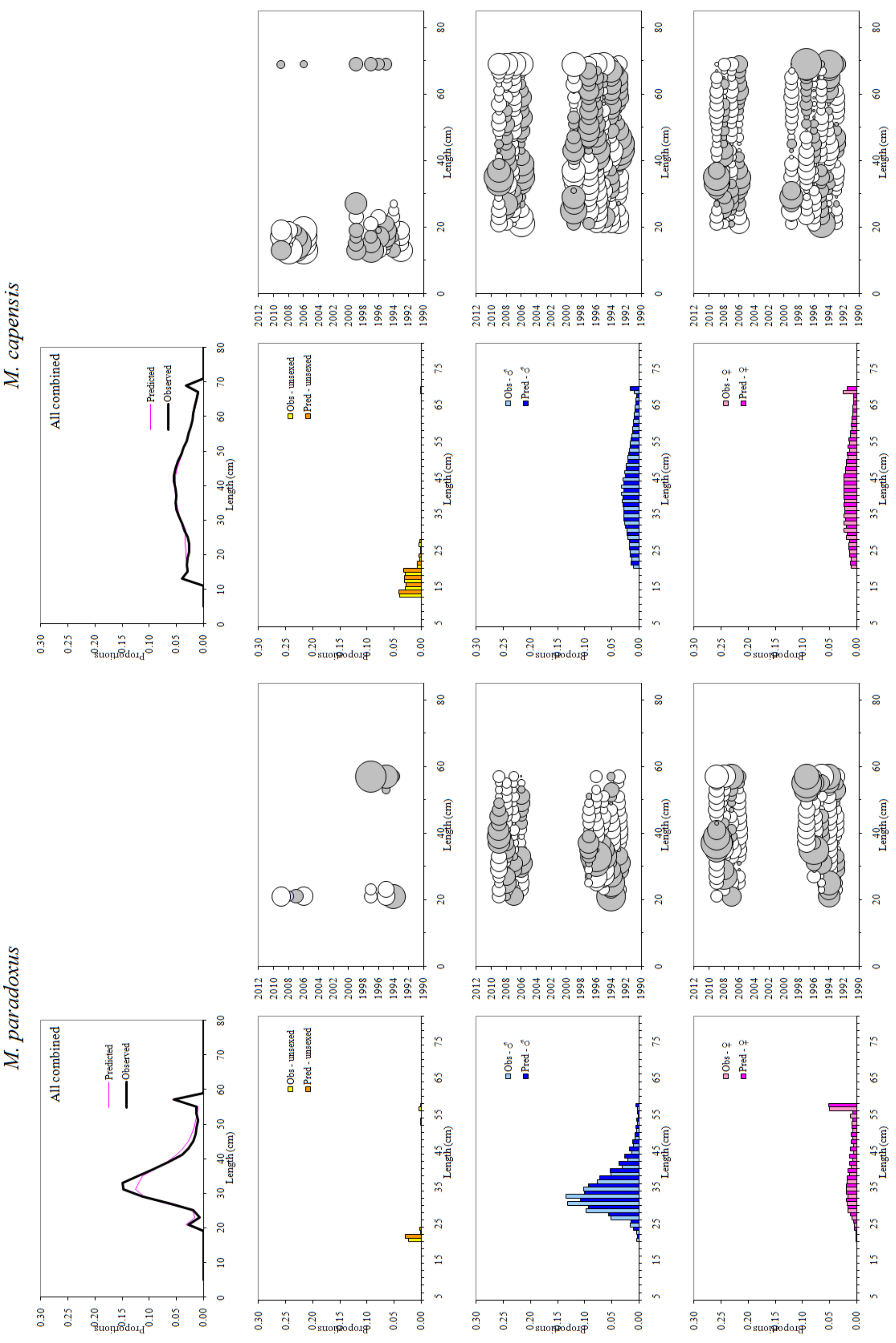
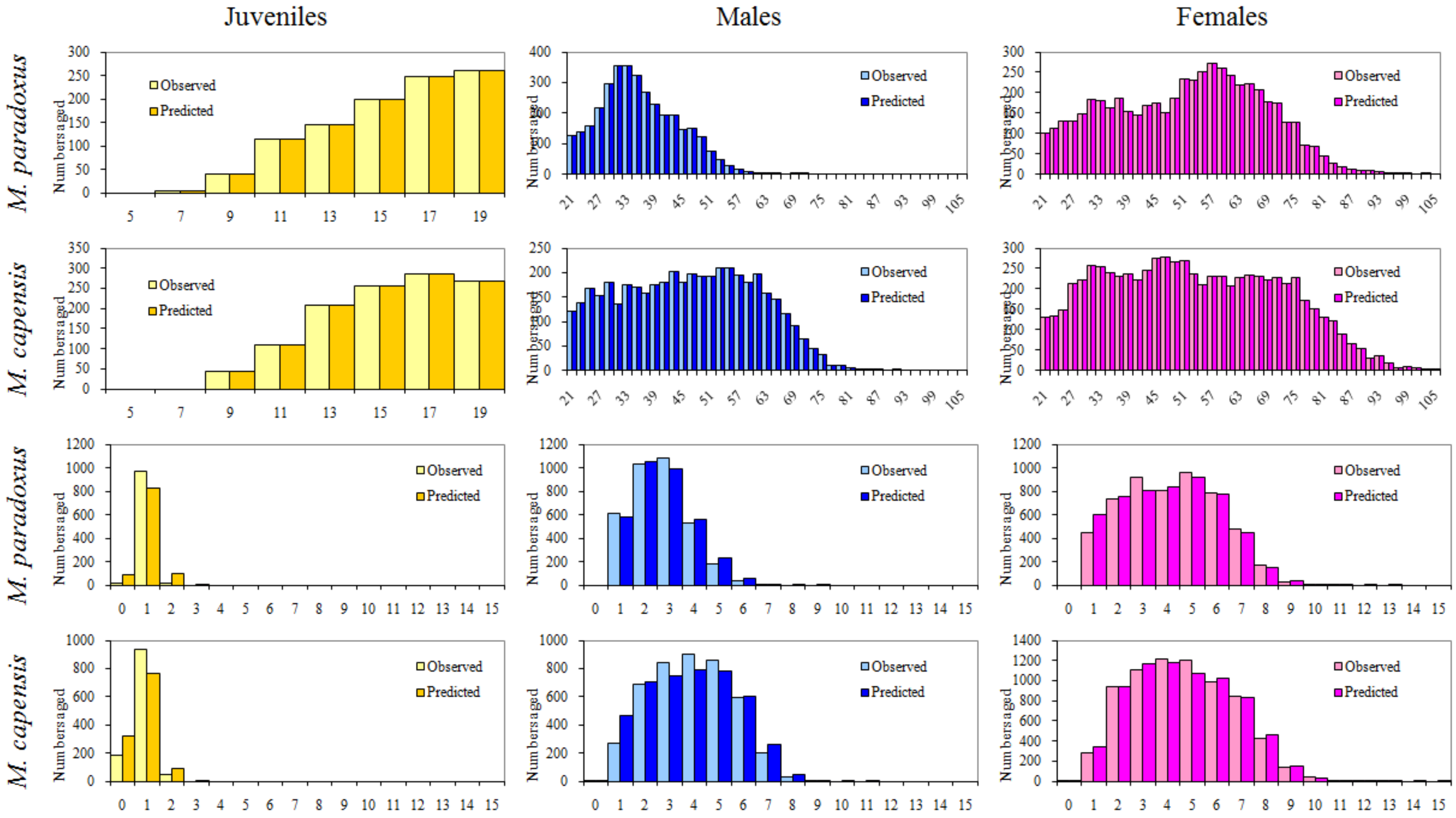


Figure 8.13: Fit of the RC to the ALKs, aggregated over all ALKs. The first two rows are summed over ages (so that model estimate and observation should be exactly equal by construction) and second two rows summed over lengths.



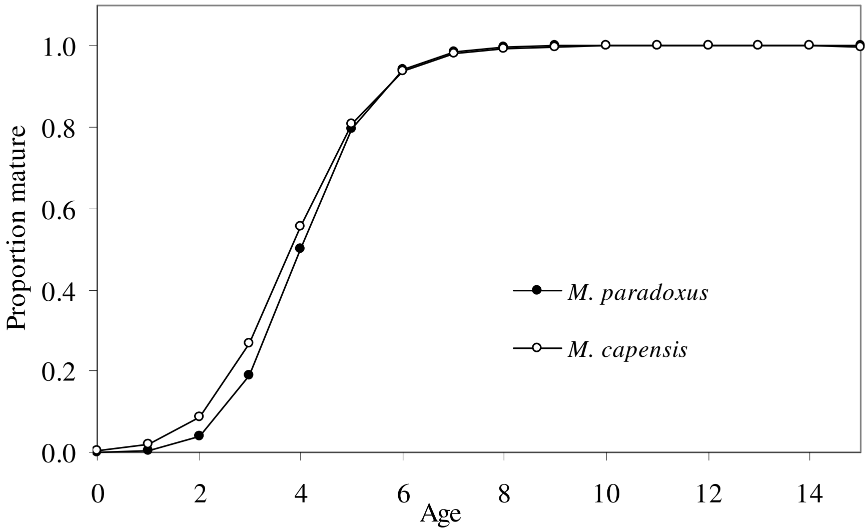
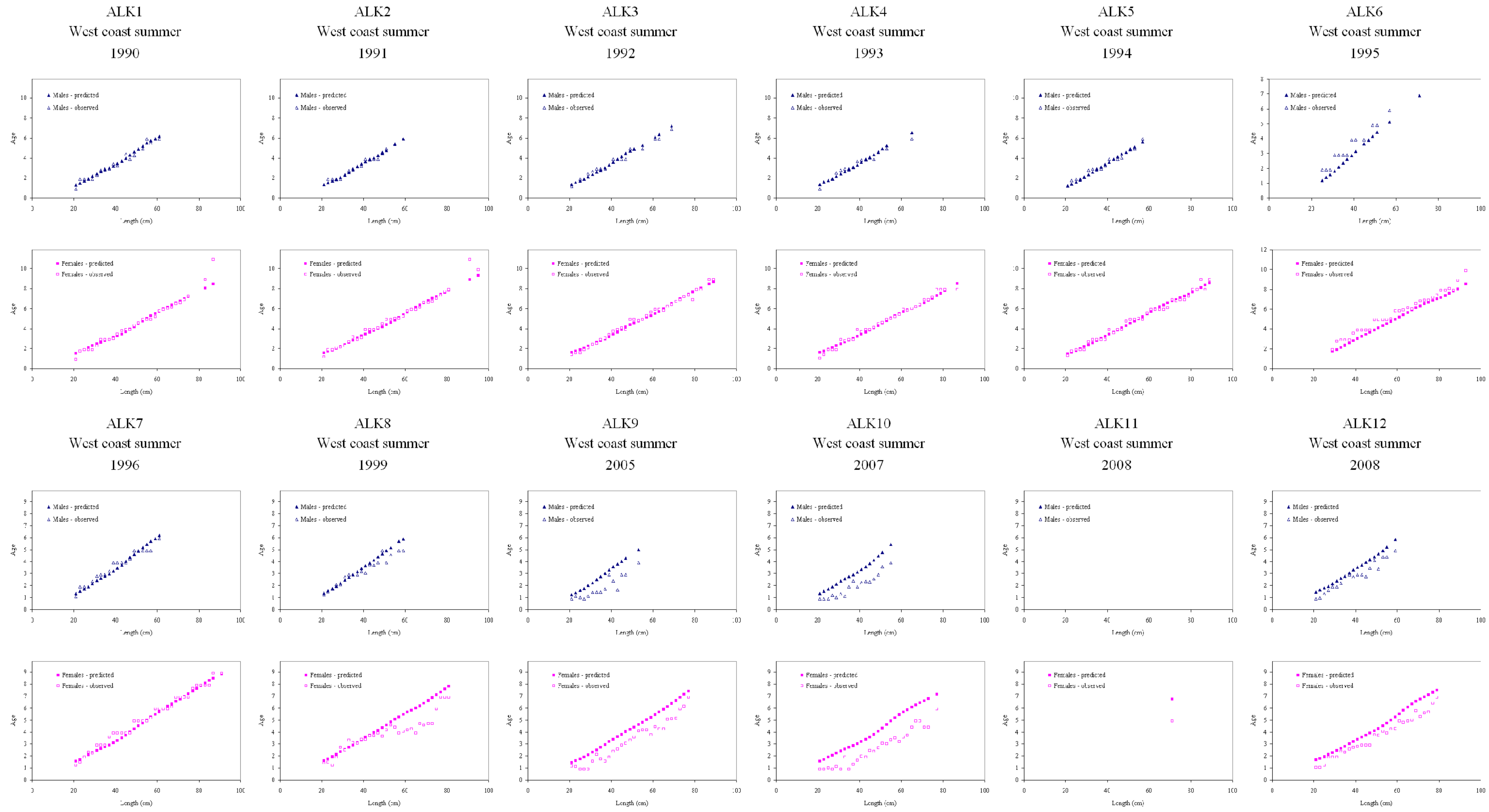


Figure 8.14: Maturity-at-age used in the new Reference Case for *M. paradoxus* and *M. capensis* (Fairweather and Leslie 2008)

Figure 8.15a: Observed vs predicted mean age-at-length for *M. paradoxus* males and females for the west coast summer surveys



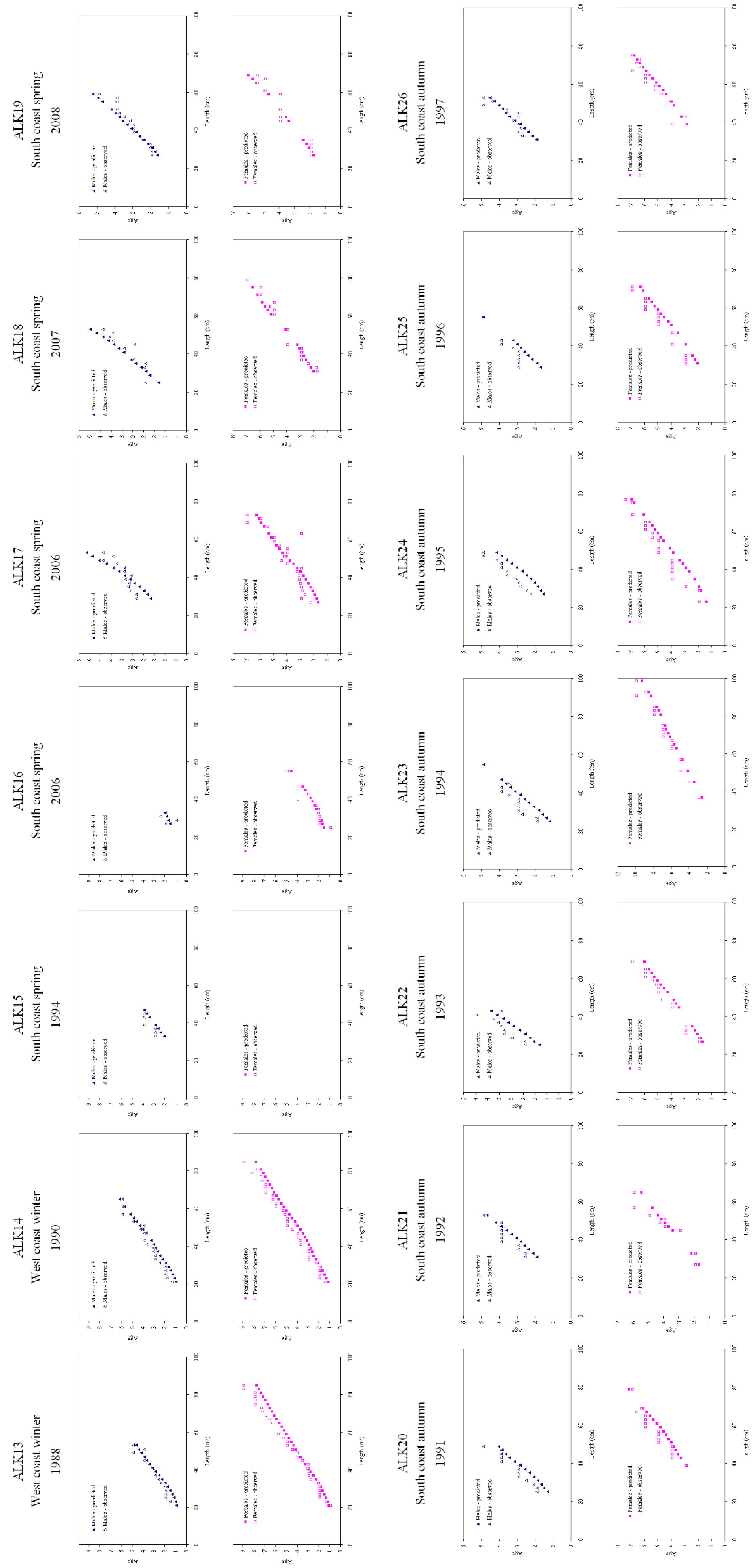
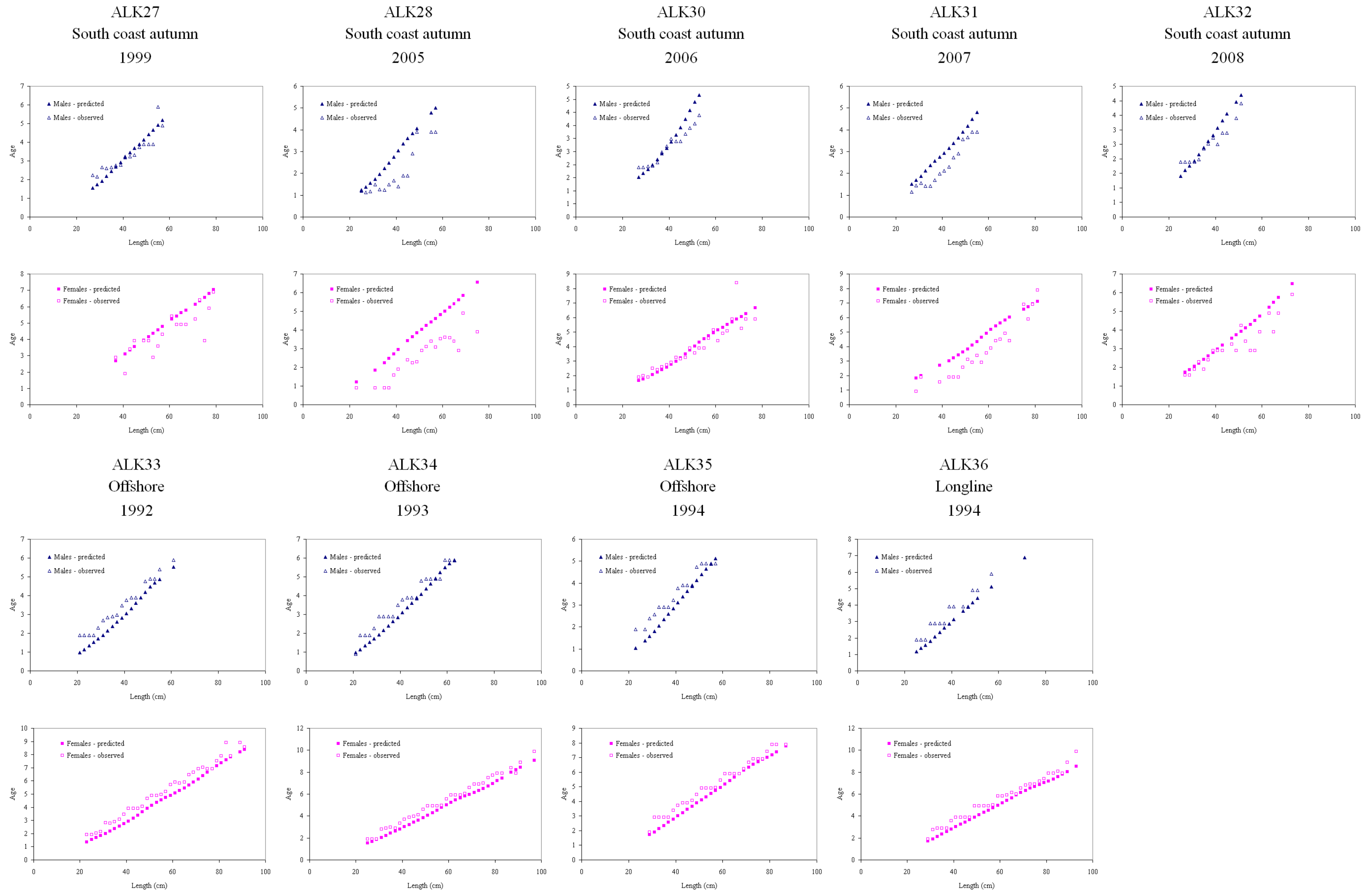


Figure 8.15b: Observed vs predicted mean age-at-length for *M. paradoxus* males and females for the West Coast winter, South Coast spring and South Coast autumn surveys.

Figure 8.15c: Observed vs predicted mean age-at-length for *M. paradoxus* males and females for the South Coast autumn surveys, offshore commercial trawl and commercial longline.



ALK27
South coast autumn
1999

ALK28
South coast autumn
2005

ALK30
South coast autumn
2006

ALK31
South coast autumn
2007

ALK32
South coast autumn
2008

ALK33
Offshore
1992

ALK34
Offshore
1993

ALK35
Offshore
1994

ALK36
Longline
1994

Figure 8.16a: Observed vs predicted mean age-at-length for *M. capensis* males and females for the West Coast summer surveys.

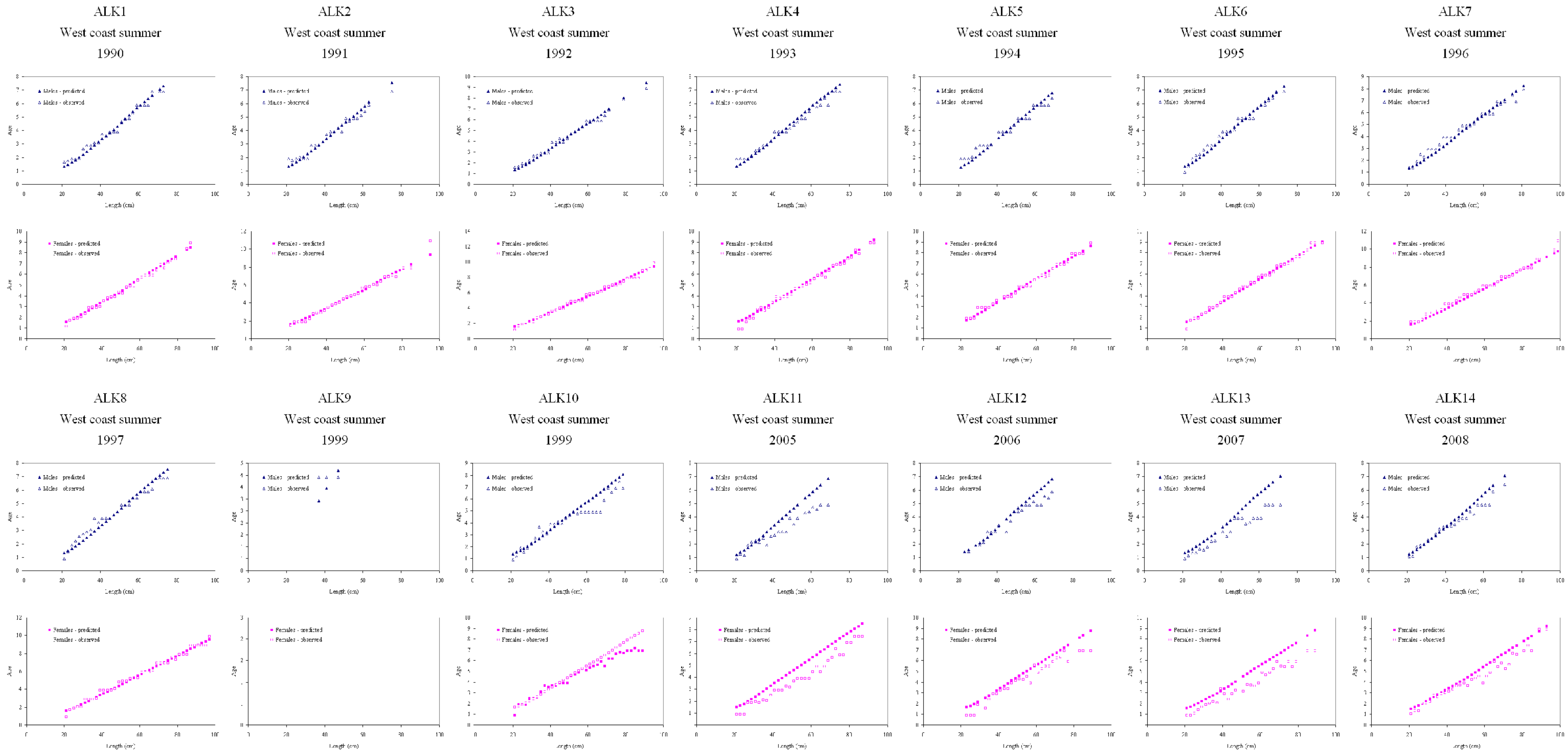
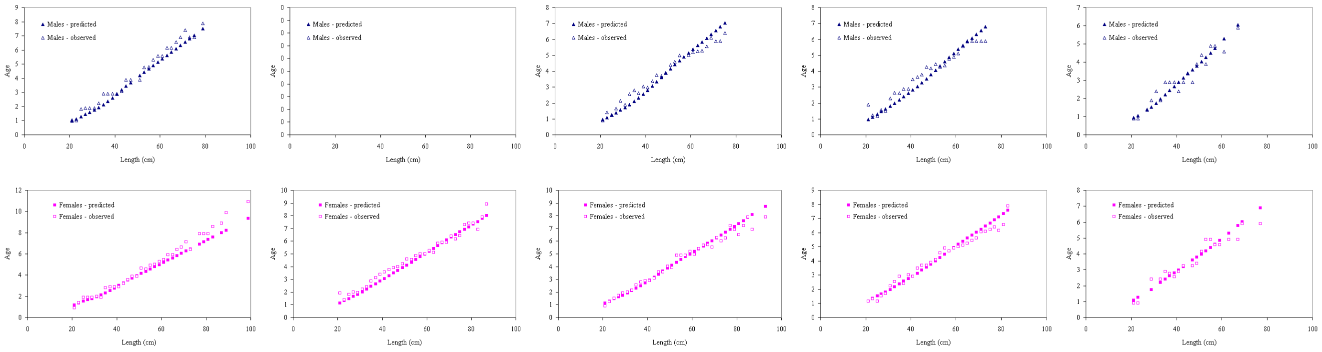


Figure 8.16b: Observed vs predicted mean age-at-length for *M. capensis* males and females for the West Coast winter, South Coast spring and South Coast autumn surveys.



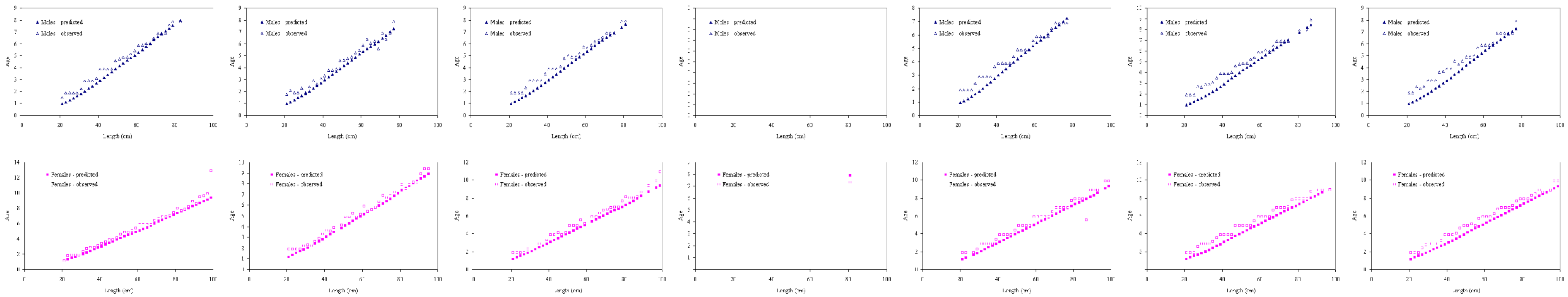
ALK15 West coast winter 1988

ALK16 South coast spring 2004

ALK17 South coast spring 2006

ALK18 South coast spring 2007

ALK19 South coast spring 2008



ALK20 South coast autumn 1991

ALK21 South coast autumn 1992

ALK22 South coast autumn 1993

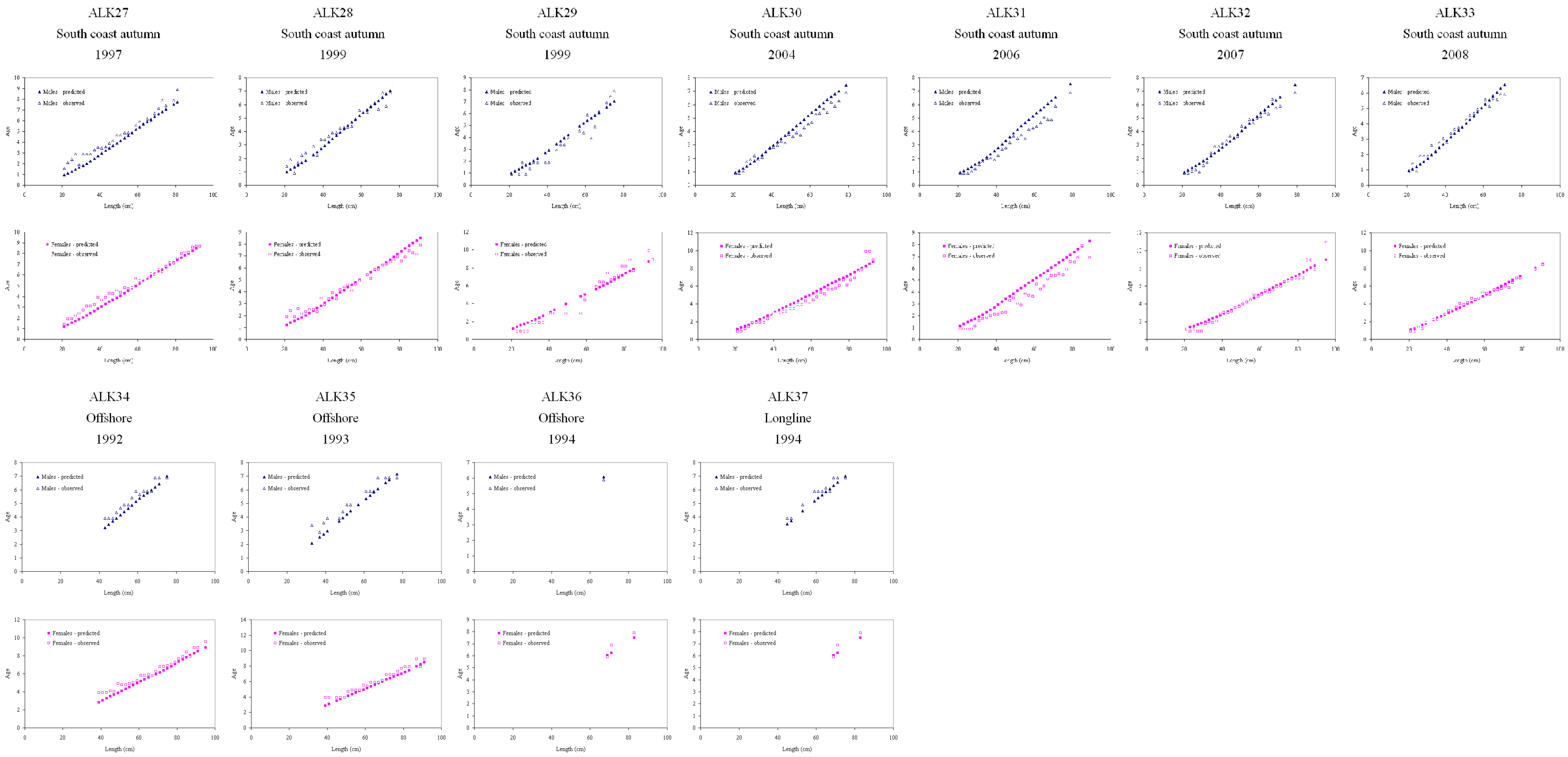
ALK23 South coast autumn 1994

ALK24 South coast autumn 1994

ALK25 South coast autumn 1995

ALK26 South coast autumn 1996

Figure 8.16c: Observed vs predicted mean age-at-length for *M. capensis* males and females for the South Coast autumn surveys, offshore commercial trawl and commercial longline.



ALK27
South coast autumn
1997

ALK28
South coast autumn
1999

ALK29
South coast autumn
1999

ALK30
South coast autumn
2004

ALK31
South coast autumn
2006

ALK32
South coast autumn
2007

ALK33
South coast autumn
2008

ALK34
Offshore
1992

ALK35
Offshore
1993

ALK36
Offshore
1994

ALK37
Longline
1994

# APPENDIX 8.I

# The data utilized

## 8.I.1 Annual catches

The species-split of the catches is carried out external to the model as described in Section 4.2.1. The size-based species proportion-by-depth relationships for the West and South coasts which are used, from 1978 onwards, to split by species the offshore trawl fleet catches have been updated by Gaylard and Bergh (2009) from research survey data. Furthermore, for the New Reference Case, the logistic function assumed for the proportion of *M. capensis* caught for the period 1917-1977 has it center at 1958 ($P_1$), with $P_2$=1.5.

The total catch in 2009 is assumed equal to the TAC for that year (118 600 tons); it is split between the different fleets and species assuming the same proportions as in 2008. The reported or assumed/estimated catches by fleet and species are given in Table App.8.I.1 and plotted in Figure App.8.I.1.

## 8.I.2 Biomass indices

Six CPUE time-series are available for assessing the status of the resource (Table App.8.I.2): a CPUE series for each of the South and West coasts developed by the International Commission for South East Atlantic Fisheries (ICSEAF 1989) and a GLM-standardised CPUE series for each coast, for each of *M. paradoxus* and *M. capensis* (Table App.8.I.2) from the offshore trawl fleet (Glazer and Butterworth 2009). The two historical CPUE series cannot be disaggregated by species, as there are no effort-by-depth data available for this pre-1978 period. The GLM standardized CPUE indices are species-specific (the catch data utilised being based on the Gaylard and Bergh (2009) algorithm).

Research surveys have been conducted on board the FRS *Africana* from 1986 in spring and/or autumn on the South Coast and from 1985 in summer and/or winter on the West Coast, and provide fully species-specific information. Since 2003, new fishing gear has occasionally been used on the *Africana*, for which a calibration factor is available. Survey biomass estimates and their estimated (sampling) standard errors are listed in Tables App.8.I.3-4 (Fairweather 2009). Only surveys extending to the deepest depth (500m) which is normally included in the survey design are considered for reasons of comparability.

The surveys conducted on the West Coast in 2000 and 2001 by the *Nansen* research vessel have not been used in this analysis. As no calibration experiments were conducted at the time, these would have to be considered as a separate series and with only two data points would hardly be informative.

## 8.I.3 Length frequencies

Survey length frequencies are available disaggregated by species and in some years disaggregated by gender (Table App.8.I.5) (Fairweather *et al.* 2009b).

Sex-aggregated proportions-at-length for each survey stratum ($p_{yl}^{surv,i}$) are provided in 1cm length classes (Fairweather *et al.* 2009b). In some instances, the proportions of males and females for a particular survey stratum and length class are available ($q_{yl}^{g,surv,i}$, where $\sum_g q_{yl}^{g,surv,i} = 1$). These are converted to survey specific (i.e. aggregated over all strata for a particular cruise) proportions-at-lengths for males ($g$=1), females ($g$=2) and unsexed ($g$=0) (with $\sum_{g=0}^{2} p_{yl}^{g,surv,i} = 1$) as follows:

The proportions-at-length are grouped into 2cm length classes.

a. For all length classes < 21 cm, the proportions-at-length are assumed to be unsexed;

b. For length classes > 20 cm:

- If there is no sex-information for either of the two 1 cm length classes to group (i.e. $\sum_g q_{yl}^{g,surv,i} = 0$ and $\sum_g q_{y,l+1}^{g,surv,i} = 0$), then the proportion for the resulting 2 cm length class is assumed to be unsexed:

$$p_{yL}^{g,surv,i} = \begin{cases} p_{yl}^{surv,i} + p_{y,l+1}^{surv,i} & \text{for } g = 0 \\ 0 & \text{for } g = 1/2 \end{cases} \qquad \text{(App.8.I.1)}$$

- If there is sex-information for one of the two 1 cm length classes to group (i.e. if $\sum_g q_{yl}^{g,surv,i} = 1$ or $\sum_g q_{y,l+1}^{g,surv,i} = 1$), then the sex-information from the one length class is used for both:

$$p_{yL}^{g,surv,i} = \begin{cases} 0 & \text{for } g = 0 \\ q_{yl}^{g,surv,i}\left(p_{yl}^{surv,i} + p_{y,l+1}^{surv,i}\right) & \text{for } g = 1/2 \end{cases} \qquad \text{(App.8.I.2)}$$

- If there is sex-information for both of the two 1 cm length classes to group (i.e. if $\sum_g q_{yl}^{g,surv,i} = 1$ and $\sum_g q_{y,l+1}^{g,surv,i} = 1$), then the sex-information is used directly:

$$p_{yL}^{g,surv,i} = \begin{cases} 0 & \text{for } g = 0 \\ q_{yl}^{g,surv,i} p_{yl}^{surv,i} + q_{y,l+1}^{g,surv,i} p_{y,l+1}^{surv,i} & \text{for } g = 1/2 \end{cases} \qquad \text{(App.8.I.3)}$$

c. The strata proportions-at-length are weighted by the estimated total number in the stratum concerned to obtain a survey specific gender-disaggregated proportions-at-length ($p_{yl}^{g,surv}$). The estimated total number in each stratum is calculated as:

$$N_y^{surv,i} = B_y^{surv,i} \big/ \overline{W}_y^{surv,i} \qquad \text{(App.8.I.4)}$$

where

$B_y^{surv,i}$ is the survey biomass estimate for stratum *i* in survey *surv*, and

$\overline{W}_y^{surv,i}$ is the mean weight of fish for stratum *i* in survey *surv*, with

$$\overline{W}_y^{surv,i} = \sum_l \left(p_{yl}^{surv,i} \alpha l^{\beta}\right) \qquad \text{(App.8.I.5)}$$

d. For each 2 cm length class, if the unsexed proportion is less than 20% of the total proportion in that length class, the sexed proportion is used to split the unsexed proportion into males and females.

The survey length frequencies available are plotted in Figures App.8.I.2-3.

Length frequency information from the commercial catch is not available by species, the reason being that it is often based on cleaned (headed and gutted) fish, which cannot be easily identified by species. As a result it is not possible to disaggregate the commercial length frequencies by species. Commercial catches-at-length for the offshore and for the inshore and longline fleets are shown in Tables App.8.II.10-12. The South Coast inshore and longline fleet catches are assumed to consist of *M. capensis* only.

## 8.I.4 Age-Length Keys

Table App.8.I.6 lists the age-length keys available. Data from animals with frills on gills (FOG) have been discarded (<3% of the total). All aged animals less or equal to 20cm in length are assumed to be juveniles, i.e. of unknown gender. The few unsexed data from animals greater than 20cm have been discarded (<1% of the total), as well as the outliers, defined as the data points lying outside the mean ± 3s.d. for each age (mean and s.d. calculated across all years and surveys). Three ALKs for *M. paradoxus* have been totally ignored in the model fitting as they seemed completely inconsistent with the other ALKs: i) 1997 West Coast summer survey, ii) 2004 West Coast summer and iii) 2006 West Coast summer. The data for these three sets are shown in Figure App.I.5.

Most otoliths are read more than once; however only one reading for each otoliths is used in the fitting procedure. Table App.8.I.7 show which reader was selected in the event of more than one reading.

Table App.8.I.1a: Species-disaggregated offshore trawl catches (in thousand tons) of South African hake from the South and West coasts (see text for details), assuming 1958 as the centre year of the shift from a primarily *M. capensis* to a primarily *M. paradoxus*.

| | *M. paradoxus* | | *M. capensis* | | | *M. paradoxus* | | *M. capensis* | | | *M. paradoxus* | | *M. capensis* | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Year | WC | SC | WC | SC | Year | WC | SC | WC | SC | Year | WC | SC | WC | SC |
| 1917 | - | - | 1.000 | - | 1948 | 0.056 | - | 58.744 | - | 1979 | 93.711 | 2.653 | 39.811 | 4.266 |
| 1918 | - | - | 1.100 | - | 1949 | 0.107 | - | 57.293 | - | 1980 | 100.723 | 2.833 | 32.805 | 3.628 |
| 1919 | - | - | 1.900 | - | 1950 | 0.260 | - | 71.740 | - | 1981 | 90.572 | 1.208 | 30.358 | 4.277 |
| 1920 | - | - | 0.000 | - | 1951 | 0.627 | - | 88.873 | - | 1982 | 84.030 | 4.063 | 29.319 | 7.294 |
| 1921 | - | - | 1.300 | - | 1952 | 1.201 | - | 87.599 | - | 1983 | 71.628 | 5.920 | 22.805 | 6.596 |
| 1922 | - | - | 1.000 | - | 1953 | 2.422 | - | 91.078 | - | 1984 | 82.940 | 4.689 | 28.316 | 6.246 |
| 1923 | - | - | 2.500 | - | 1954 | 5.149 | - | 100.251 | - | 1985 | 93.192 | 10.054 | 31.878 | 9.962 |
| 1924 | - | - | 1.500 | - | 1955 | 10.343 | - | 105.057 | - | 1986 | 105.097 | 9.974 | 28.708 | 5.991 |
| 1925 | - | - | 1.900 | - | 1956 | 18.540 | - | 99.660 | - | 1987 | 95.954 | 9.495 | 21.571 | 6.189 |
| 1926 | - | - | 1.400 | - | 1957 | 32.241 | - | 94.159 | - | 1988 | 83.910 | 7.184 | 22.672 | 7.332 |
| 1927 | - | - | 0.800 | - | 1958 | 49.136 | - | 81.564 | - | 1989 | 84.719 | 6.919 | 22.541 | 11.993 |
| 1928 | - | - | 2.600 | - | 1959 | 72.535 | - | 73.465 | - | 1990 | 89.976 | 11.636 | 13.660 | 11.155 |
| 1929 | - | - | 3.800 | - | 1960 | 95.147 | - | 64.753 | - | 1991 | 92.787 | 9.604 | 13.663 | 12.470 |
| 1930 | - | - | 4.400 | - | 1961 | 98.478 | - | 50.222 | - | 1992 | 89.638 | 19.260 | 13.649 | 7.202 |
| 1931 | - | - | 2.800 | - | 1962 | 103.768 | - | 43.832 | - | 1993 | 107.370 | 11.143 | 10.694 | 3.117 |
| 1932 | - | - | 14.300 | - | 1963 | 123.055 | - | 46.445 | - | 1994 | 112.355 | 7.842 | 11.512 | 3.210 |
| 1933 | - | - | 11.100 | - | 1964 | 119.837 | - | 42.463 | - | 1995 | 104.842 | 4.486 | 16.055 | 2.664 |
| 1934 | - | - | 13.800 | - | 1965 | 151.211 | - | 51.789 | - | 1996 | 119.889 | 10.467 | 9.286 | 2.822 |
| 1935 | - | - | 15.000 | - | 1966 | 145.914 | - | 49.086 | - | 1997 | 108.917 | 12.902 | 8.237 | 2.934 |
| 1936 | - | - | 17.700 | - | 1967 | 132.530 | 5.391 | 44.170 | 8.795 | 1998 | 115.290 | 11.165 | 12.363 | 2.988 |
| 1937 | - | - | 20.200 | - | 1968 | 107.834 | 10.619 | 35.766 | 17.289 | 1999 | 90.030 | 12.749 | 13.731 | 2.597 |
| 1938 | - | - | 21.100 | - | 1969 | 124.056 | 14.442 | 41.044 | 23.489 | 2000 | 91.366 | 8.777 | 26.336 | 4.753 |
| 1939 | - | - | 20.000 | - | 1970 | 107.108 | 9.035 | 35.392 | 14.688 | 2001 | 98.164 | 8.213 | 19.433 | 7.944 |
| 1940 | - | - | 28.600 | - | 1971 | 151.855 | 11.472 | 50.145 | 18.644 | 2002 | 95.122 | 13.629 | 9.809 | 4.955 |
| 1941 | - | - | 30.600 | - | 1972 | 183.394 | 17.789 | 60.539 | 28.907 | 2003 | 95.062 | 20.503 | 10.314 | 4.530 |
| 1942 | 0.001 | - | 34.499 | - | 1973 | 118.629 | 27.566 | 39.153 | 44.790 | 2004 | 86.340 | 28.805 | 11.891 | 5.965 |
| 1943 | 0.001 | - | 37.899 | - | 1974 | 92.480 | 34.613 | 30.520 | 56.240 | 2005 | 88.722 | 24.374 | 6.545 | 4.872 |
| 1944 | 0.002 | - | 34.098 | - | 1975 | 67.381 | 25.703 | 22.236 | 41.760 | 2006 | 84.951 | 19.923 | 8.547 | 4.705 |
| 1945 | 0.004 | - | 29.196 | - | 1976 | 108.192 | 19.785 | 35.702 | 32.145 | 2007 | 96.426 | 14.899 | 12.444 | 2.345 |
| 1946 | 0.010 | - | 40.390 | - | 1977 | 76.939 | 14.086 | 25.389 | 22.886 | 2008 | 92.445 | 13.861 | 6.930 | 3.646 |
| 1947 | 0.020 | - | 41.380 | - | 1978 | 103.665 | 3.830 | 23.847 | 3.755 | 2009 | 85.357 | 12.798 | 6.399 | 3.366 |

Table App.8.II.1b: Inshore trawl catches of South African hake (assumed to be *M. capensis* exclusively) from the South Coast.

| Year | *M. capensis* | Year | *M. capensis* | Year | *M. capensis* |
|---|---|---|---|---|---|
| 1960 | 1.000 | 1977 | 3.500 | 1994 | 9.569 |
| 1961 | 1.308 | 1978 | 4.931 | 1995 | 10.630 |
| 1962 | 1.615 | 1979 | 6.093 | 1996 | 11.062 |
| 1963 | 1.923 | 1980 | 9.121 | 1997 | 8.834 |
| 1964 | 2.231 | 1981 | 9.400 | 1998 | 8.283 |
| 1965 | 2.538 | 1982 | 8.089 | 1999 | 8.595 |
| 1966 | 2.846 | 1983 | 7.672 | 2000 | 10.906 |
| 1967 | 3.154 | 1984 | 9.035 | 2001 | 11.836 |
| 1968 | 3.462 | 1985 | 9.203 | 2002 | 9.581 |
| 1969 | 3.769 | 1986 | 8.724 | 2003 | 9.883 |
| 1970 | 4.077 | 1987 | 8.607 | 2004 | 10.004 |
| 1971 | 4.385 | 1988 | 8.417 | 2005 | 7.881 |
| 1972 | 4.692 | 1989 | 10.038 | 2006 | 5.524 |
| 1973 | 5.000 | 1990 | 10.012 | 2007 | 6.350 |
| 1974 | 10.056 | 1991 | 8.206 | 2008 | 5.496 |
| 1975 | 6.372 | 1992 | 9.252 | 2009 | 5.075 |
| 1976 | 5.740 | 1993 | 8.870 | | |

Table App.8.II.1c: Species-disaggregated longline trawl catches of South African hake from the South and West coasts.

| | *M. para* | *M. capensis* | | | *M. para* | *M. capensis* | | | *M. para* | *M. capensis* | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| Year | WC | WC | SC | Year | WC | WC | SC | Year | WC | WC | SC |
| 1983 | 0.161 | 0.069 | - | 1992 | - | - | 1.500 | 2001 | 2.793 | 1.197 | 1.688 |
| 1984 | 0.256 | 0.110 | 0.016 | 1993 | - | - | - | 2002 | 4.772 | 2.045 | 3.945 |
| 1985 | 0.817 | 0.350 | 0.292 | 1994 | 1.130 | 0.484 | 0.626 | 2003 | 4.668 | 2.000 | 4.878 |
| 1986 | 0.965 | 0.413 | 0.302 | 1995 | 0.670 | 0.287 | 0.650 | 2004 | 3.758 | 1.611 | 4.429 |
| 1987 | 2.500 | 1.071 | 0.353 | 1996 | 1.676 | 0.718 | 1.828 | 2005 | 4.172 | 1.788 | 4.559 |
| 1988 | 3.628 | 1.555 | 0.331 | 1997 | 1.806 | 0.774 | 1.872 | 2006 | 3.592 | 1.539 | 4.032 |
| 1989 | 0.203 | 0.087 | 0.032 | 1998 | 0.647 | 0.277 | 1.471 | 2007 | 3.151 | 1.350 | 3.834 |
| 1990 | 0.270 | 0.116 | - | 1999 | 1.963 | 0.841 | 4.144 | 2008 | 2.170 | 0.930 | 2.740 |
| 1991 | - | - | 3.000 | 2000 | 3.456 | 1.481 | 2.077 | 2009 | 2.004 | 0.859 | 2.530 |

Table App.8.II.1d: Handline catches of South African hake (assumed to be *M. capensis* exclusively) from the South Coast.

| Year | *M. capensis* | Year | *M. capensis* | Year | *M. capensis* |
|---|---|---|---|---|---|
| 1985 | 0.065 | 1994 | 0.449 | 2003 | 3.000 |
| 1986 | 0.084 | 1995 | 0.756 | 2004 | 1.600 |
| 1987 | 0.096 | 1996 | 1.515 | 2005 | 0.700 |
| 1988 | 0.071 | 1997 | 1.404 | 2006 | 0.400 |
| 1989 | 0.137 | 1998 | 1.738 | 2007 | 0.400 |
| 1990 | 0.348 | 1999 | 2.749 | 2008 | 0.231 |
| 1991 | 1.270 | 2000 | 5.500 | 2009 | 0.213 |
| 1992 | 1.099 | 2001 | 7.300 | | |
| 1993 | 0.278 | 2002 | 3.500 | | |

Table App.8.I.2: South and West Coast historic (ICSEAF 1989) and GLM standardized CPUE data (GLM3 of Glazer and Butterworth 2009) for *M. paradoxus* and *M. capensis*. The historic CPUE series are for *M. capensis* and *M. paradoxus* combined.

| | ICSEAF CPUE (t hr$^{-1}$) | | | GLM CPUE (kg min$^{-1}$) | | | |
|---|---|---|---|---|---|---|---|
| | Species-aggregated | | | *M. paradoxus* | | *M. capensis* | |
| Year | West Coast | South Coast | Year | West Coast | South Coast | West Coast | South Coast |
| 1955 | 17.31 | | 1978 | 3.90 | 0.76 | 0.85 | 2.10 |
| 1956 | 15.64 | | 1979 | 3.83 | 0.71 | 1.36 | 2.08 |
| 1957 | 16.47 | | 1980 | 3.59 | 1.12 | 1.17 | 2.61 |
| 1958 | 16.26 | | 1981 | 3.56 | 0.69 | 1.21 | 2.25 |
| 1959 | 16.26 | | 1982 | 3.49 | 0.99 | 1.05 | 2.28 |
| 1960 | 17.31 | | 1983 | 3.78 | 1.10 | 1.37 | 2.68 |
| 1961 | 12.09 | | 1984 | 3.91 | 1.17 | 1.45 | 3.13 |
| 1962 | 14.18 | | 1985 | 4.39 | 1.69 | 1.77 | 3.82 |
| 1963 | 13.97 | | 1986 | 3.99 | 1.66 | 1.32 | 3.10 |
| 1964 | 14.60 | | 1987 | 3.32 | 1.64 | 1.08 | 2.74 |
| 1965 | 10.84 | | 1988 | 3.36 | 1.15 | 0.94 | 3.12 |
| 1966 | 10.63 | | 1989 | 3.59 | 1.09 | 1.04 | 3.56 |
| 1967 | 10.01 | | 1990 | 4.21 | 1.76 | 0.62 | 3.97 |
| 1968 | 10.01 | | 1991 | 4.45 | 0.95 | 0.87 | 4.55 |
| 1969 | 8.62 | 1.28 | 1992 | 3.86 | 2.06 | 1.15 | 3.50 |
| 1970 | 7.23 | 1.22 | 1993 | 3.90 | 1.96 | 1.05 | 2.28 |
| 1971 | 7.09 | 1.14 | 1994 | 4.47 | 1.53 | 1.08 | 2.96 |
| 1972 | 4.90 | 0.64 | 1995 | 3.59 | 0.95 | 1.45 | 3.15 |
| 1973 | 4.97 | 0.56 | 1996 | 4.52 | 1.77 | 1.06 | 2.48 |
| 1974 | 4.65 | 0.54 | 1997 | 3.90 | 2.30 | 1.04 | 2.18 |
| 1975 | 4.66 | 0.37 | 1998 | 3.97 | 1.84 | 1.61 | 2.25 |
| 1976 | 5.35 | 0.40 | 1999 | 3.10 | 2.11 | 1.71 | 2.56 |
| 1977 | 4.84 | 0.42 | 2000 | 2.42 | 1.40 | 1.90 | 2.55 |
| | | | 2001 | 2.10 | 1.46 | 1.28 | 1.89 |
| | | | 2002 | 2.47 | 1.25 | 0.78 | 2.22 |
| | | | 2003 | 2.47 | 1.90 | 0.93 | 2.04 |
| | | | 2004 | 2.08 | 1.32 | 0.81 | 1.92 |
| | | | 2005 | 2.21 | 1.31 | 0.48 | 1.51 |
| | | | 2006 | 2.36 | 1.36 | 0.56 | 1.20 |
| | | | 2007 | 2.74 | 1.44 | 0.60 | 1.06 |
| | | | 2008 | 3.44 | 1.38 | 0.50 | 1.67 |

Table App.8.I.3: Survey biomass estimates and associated standard errors in thousand tons for *M. paradoxus* for the depth range 0-500m for the South Coast and for the West Coast. Values in bold are for the surveys conducted by the *Africana* with the new gear.

| | West coast | | | | South coast | | | |
|---|---|---|---|---|---|---|---|---|
| Year | Summer | | Winter | | Spring (Sept) | | Autumn (Apr/May) | |
| | Biomass | (s.e.) | Biomass | (s.e.) | Biomass | (s.e.) | Biomass | (s.e.) |
| 1985 | 169.959 | (36.680) | 264.839 | (52.949) | - | - | - | - |
| 1986 | 196.111 | (36.358) | 172.477 | (24.122) | 13.758 | (3.554) | - | - |
| 1987 | 284.805 | (53.101) | 195.482 | (44.415) | 21.554 | (4.605) | - | - |
| 1988 | 158.758 | (27.383) | 233.041 | (64.003) | - | - | 30.316 | (11.104) |
| 1989 | - | - | 468.780 | (124.830) | - | - | - | - |
| 1990 | 282.174 | (78.945) | 226.862 | (46.007) | - | - | - | - |
| 1991 | 327.020 | (82.180) | - | - | - | - | 26.638 | (10.460) |
| 1992 | 226.687 | (32.990) | - | - | - | - | 24.304 | (15.195) |
| 1993 | 334.151 | (50.234) | - | - | - | - | 198.849 | (98.452) |
| 1994 | 330.270 | (58.319) | - | - | - | - | 111.469 | (34.627) |
| 1995 | 324.554 | (80.357) | - | - | - | - | 55.068 | (22.380) |
| 1996 | 430.908 | (80.604) | - | - | - | - | 85.546 | (25.484) |
| 1997 | 569.957 | (108.200) | - | - | - | - | 135.192 | (51.031) |
| 1998 | - | - | - | - | - | - | - | - |
| 1999 | 562.859 | (116.302) | - | - | - | - | 321.478 | (113.557) |
| 2000 | - | - | - | - | - | - | - | - |
| 2001 | - | - | - | - | 19.929 | (9.956) | - | - |
| 2002 | 267.487 | (35.068) | - | - | - | - | - | - |
| 2003 | 411.177 | (69.431) | - | - | **88.442** | (36.051) | 108.857 | (37.528) |
| 2004 | **259.527** | (56.021) | - | - | **63.900** | (17.894) | **48.898** | (20.343) |
| 2005 | **286.416** | (39.849) | - | - | - | - | **26.605** | (7.952) |
| 2006 | 315.310 | (49.490) | - | - | 72.415 | (15.500) | 34.799 | (8.325) |
| 2007 | **392.812** | (70.043) | - | - | **52.287** | (19.231) | **129.646** | (60.661) |
| 2008 | **246.542** | (51.973) | - | - | **24.816** | (8.775) | **39.505** | (11.408) |
| 2009 | **330.235** | (28.526) | - | - | - | - | **102.834** | (28.670) |

Table App.8.I.4: Survey biomass estimates and associated standard errors in thousand tons for *M. capensis* for the depth range 0-500m for the South Coast and for the West Coast. Values in bold are for the surveys conducted by the *Africana* with the new gear.

| | West coast | | | | South coast | | | |
|---|---|---|---|---|---|---|---|---|
| Year | Summer | | Winter | | Spring (Sept) | | Autumn (Apr/May) | |
| | Biomass | (s.e.) | Biomass | (s.e.) | Biomass | (s.e.) | Biomass | (s.e.) |
| 1985 | 124.647 | (22.707) | 181.487 | (27.476) | - | - | - | - |
| 1986 | 117.810 | (23.636) | 119.587 | (18.489) | 121.197 | (16.625) | - | - |
| 1987 | 75.693 | (10.241) | 87.391 | (11.198) | 159.088 | (17.233) | - | - |
| 1988 | 66.725 | (10.765) | 47.120 | (9.568) | - | - | 165.939 | (21.871) |
| 1989 | - | - | 323.833 | (67.295) | - | - | - | - |
| 1990 | 455.798 | (135.237) | 157.800 | (23.561) | - | - | - | - |
| 1991 | 77.357 | (14.995) | - | - | - | - | 274.298 | (44.395) |
| 1992 | 95.407 | (11.744) | - | - | - | - | 138.085 | (15.357) |
| 1993 | 92.598 | (14.589) | - | - | - | - | 158.340 | (13.733) |
| 1994 | 121.257 | (35.951) | - | - | - | - | 160.555 | (23.701) |
| 1995 | 199.142 | (26.812) | - | - | - | - | 236.025 | (31.840) |
| 1996 | 83.337 | (9.285) | - | - | - | - | 244.410 | (25.107) |
| 1997 | 257.293 | (46.056) | - | - | - | - | 183.087 | (18.906) |
| 1998 | - | - | - | - | - | - | - | - |
| 1999 | 198.716 | (32.467) | - | - | - | - | 191.203 | (14.952) |
| 2000 | - | - | - | - | - | - | - | - |
| 2001 | - | - | - | - | 133.793 | (20.858) | - | - |
| 2002 | 106.253 | (15.813) | - | - | - | - | - | - |
| 2003 | 75.960 | (13.314) | - | - | **82.928** | (9.010) | 128.450 | (20.062) |
| 2004 | **205.939** | (33.216) | - | - | **106.119** | (15.596) | **99.902** | (12.027) |
| 2005 | **70.983** | (13.845) | - | - | - | - | **76.932** | (5.965) |
| 2006 | 88.420 | (22.851) | - | - | 99.867 | (9.803) | 130.900 | (14.816) |
| 2007 | **82.270** | (11.441) | - | - | **74.615** | (7.383) | **70.940** | (5.615) |
| 2008 | **50.877** | (5.355) | - | - | **94.232** | (11.456) | **108.195** | (9.978) |
| 2009 | **175.289** | (39.920) | - | - | - | - | **124.004** | (11.808) |

Table App.8.I.5: Survey length frequencies available in February 2010.

| Year | West coast | | | | South coast | | | |
|---|---|---|---|---|---|---|---|---|
| | Summer | | Winter | | Spring (Sept) | | Autumn (Apr/May) | |
| | Sex-aggr. | By sex | Sex-aggr. | By sex | Sex-aggr. | By sex | Sex-aggr. | By sex |
| 1985 | ✓ | - | ✓ | - | - | - | - | - |
| 1986 | ✓ | - | ✓ | - | ✓ | - | - | - |
| 1987 | ✓ | - | ✓ | - | ✓ | - | - | - |
| 1988 | ✓ | - | ✓ | - | - | - | ✓ | - |
| 1989 | - | - | ✓ | - | - | - | - | - |
| 1990 | ✓ | - | ✓ | - | - | - | - | - |
| 1991 | ✓ | - | - | - | - | - | ✓ | - |
| 1992 | ✓ | - | - | - | - | - | ✓ | - |
| 1993 | ✓ | ✓ | - | - | - | - | ✓ | ✓ |
| 1994 | ✓ | ✓ | - | - | - | - | ✓ | ✓ |
| 1995 | ✓ | ✓ | - | - | - | - | ✓ | ✓ |
| 1996 | ✓ | ✓ | - | - | - | - | ✓ | ✓ |
| 1997 | ✓ | ✓ | - | - | - | - | ✓ | ✓ |
| 1998 | - | - | - | - | - | - | - | - |
| 1999 | ✓ | ✓ | - | - | - | - | ✓ | - |
| 2000 | - | - | - | - | - | - | - | - |
| 2001 | - | - | - | - | ✓ | - | - | - |
| 2002 | ✓ | - | - | - | - | - | - | - |
| 2003 | ✓ | - | - | - | ✓ | - | ✓ | - |
| 2004 | ✓ | - | - | - | ✓ | - | ✓ | - |
| 2005 | ✓ | - | - | - | - | - | ✓ | - |
| 2006 | ✓ | ✓ | - | - | ✓ | ✓ | ✓ | ✓ |
| 2007 | ✓ | ✓ | - | - | ✓ | ✓ | ✓ | ✓ |
| 2008 | ✓ | ✓ | - | - | ✓ | ✓ | ✓ | ✓ |
| 2009 | ✓ | ✓ | - | - | - | - | ✓ | ✓ |

Table App.8.I.6: Species- and sex-disaggregated age and length data available in February 2010 by reader.

| | | *M. paradoxus* | | | | | | | | | | *M. capensis* | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | Year | UR | AD | LB | KG | JP | AP | DJ | PM | TA | KB | UR | AD | LB | KG | JP | AP | DJ | PM | TA | KB |
| West coast summer survey | 1990 | 351 | | | | | | | | | | 354 | | | | | | | | | |
| | 1991 | 349 | | | | | | | | | | 384 | | | | | | | | | |
| | 1992 | | | | 310 | 310 | 44 | | | | | | | | 390 | 389 | 33 | | | | |
| | 1993 | | | | 313 | 311 | | 49 | | | | 2 | | | 353 | 352 | | 62 | | | |
| | 1994 | | | | 290 | 290 | | 4 | | | | | | | 282 | 282 | | 6 | | | |
| | 1995 | | | | | 303 | | | | | 303 | | | | | 368 | | | | | 368 |
| | 1996 | 292 | | | | | | | | | | 365 | | | | | | | | | |
| | 1997 | 333 | | 334 | | | | | | | | 334 | | | | | | | | | |
| | 1999 | 268 | 307 | 299 | | | | | | | | 319 | 352 | 359 | | | | | | | |
| | 2004 | | | 506 | | | | | | | | | | | | | | | | | |
| | 2005 | | | 354 | | | | | | | | | 340 | | | | | | | | |
| | 2006 | | 465 | 468 | | | | | | | | | 163 | | | | | | | | |
| | 2007 | | 557 | 554 | | | | | | | | | 369 | 372 | | | | | | | |
| | 2008 | | 412 | 409 | | | | | | | | | 475 | 453 | | | | | | | |
| West coast winter survey | 1988 | 471 | | | | | | | | | | 354 | | | | | | | | | |
| | 1990 | 303 | | | | | | | | | | | | | | | | | | | |
| South coast spring survey | 1994 | 10 | | | | | | | | | | | | | | | | | | | |
| | 2004 | | | | | | | | | | | | 808 | 808 | | | | | | | |
| | 2006 | | 489 | 243 | | | | | | | | | 512 | | | | | | | | |
| | 2007 | | 116 | | | | | | | | | | 441 | | | | | | | | |
| | 2008 | | 149 | | | | | | | | | | 127 | | | | | | | | |
| South coast autumn survey | 1991 | 109 | | | | | | | | | | 421 | | | | | | | | | |
| | 1992 | | | | 40 | 40 | 5 | | | | | | | | 329 | 329 | 91 | | | | |
| | 1993 | | | | 95 | 95 | | 23 | | | | | | | 407 | 407 | | 40 | | | |
| | 1994 | | | | 95 | 69 | | 27 | | | | 5 | | | 390 | 391 | | 83 | | | |
| | 1995 | 95 | | | | | | | | | | 404 | | | | | | | | | |
| | 1996 | 60 | | | | | | | | | | 373 | | | | | | | | | |
| | 1997 | 85 | | | | | | | | | | 387 | | | | | | | | | |
| | 1999 | | 139 | 139 | | | | | 140 | 140 | 140 | | 266 | 264 | | | | | 408 | 406 | 400 |
| | 2004 | | | | | | | | | | | | 508 | | | | | | | | |
| | 2005 | | 194 | 193 | | | | | | | | | | | | | | | | | |
| | 2006 | | 444 | 358 | | | | | | | | | | 740 | | | | | | | |
| | 2007 | | 215 | 214 | | | | | | | | | 629 | 626 | | | | | | | |
| | 2008 | | 137 | | | | | | | | | | 643 | 643 | | | | | | | |
| Offshore commercial | 1992 | | | | 521 | 521 | 46 | | | | | | | | 260 | 260 | 28 | | | | |
| | 1993 | | | | 645 | 646 | | 75 | | | | | | | 115 | 115 | | 17 | | | |
| | 1994 | | | | 330 | 330 | | 38 | | | | 5 | | | | | | | | | |
| Longline comm. | 1994 | | | | 314 | 314 | | 9 | | | | | | | 131 | 126 | | 5 | | | |

Table App.8.I.7: For each set of age readers, the reader shaded is the one whose otolith readings were used.

*M. paradoxus*

| | | | |
|---|---|---|---|
| 1 | UR | | |
| 2 | KG | JP | AP/DJ |
| 3 | UR | AD | LB |
| 4 | AD | | |
| 5 | JP | KB | |

*M. capensis*

| | | | | | |
|---|---|---|---|---|---|
| 1 | UR | | | | |
| 2 | KG | JP | AP/DJ | | |
| 3 | JP | KB | | | |
| 4 | UR | AD | LB | | |
| 5 | AD | LB | PM | TA | KB |
| 6 | PM | TA | KB | | |
| 5 | LB | | | | |

The readers are: Alexia Daniels (AD), Luke Bester (LB), 'Unknown Reader' (UR), Kevin Gradie (KG), John Prinsloo (JP), Andy Payne/Dave Japp (AP/DJ), Phoeby Mullins (PM), Teressa Akkers (TA) and Kashif Booley (KB).

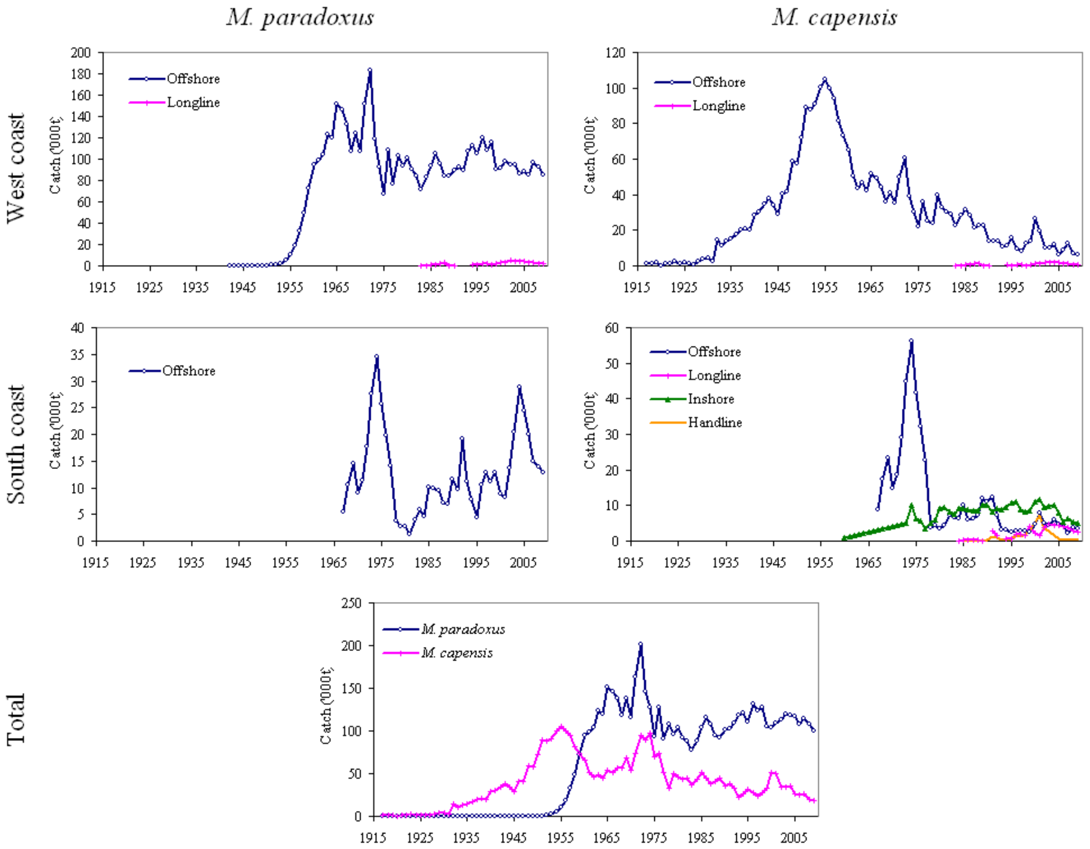


Figure App.8.I.1: Annual catches, see text for details, assuming 1958 as the centre year of the shift from a primarily *M. capensis* to a primarily *M. paradoxus* offshore trawl catch.

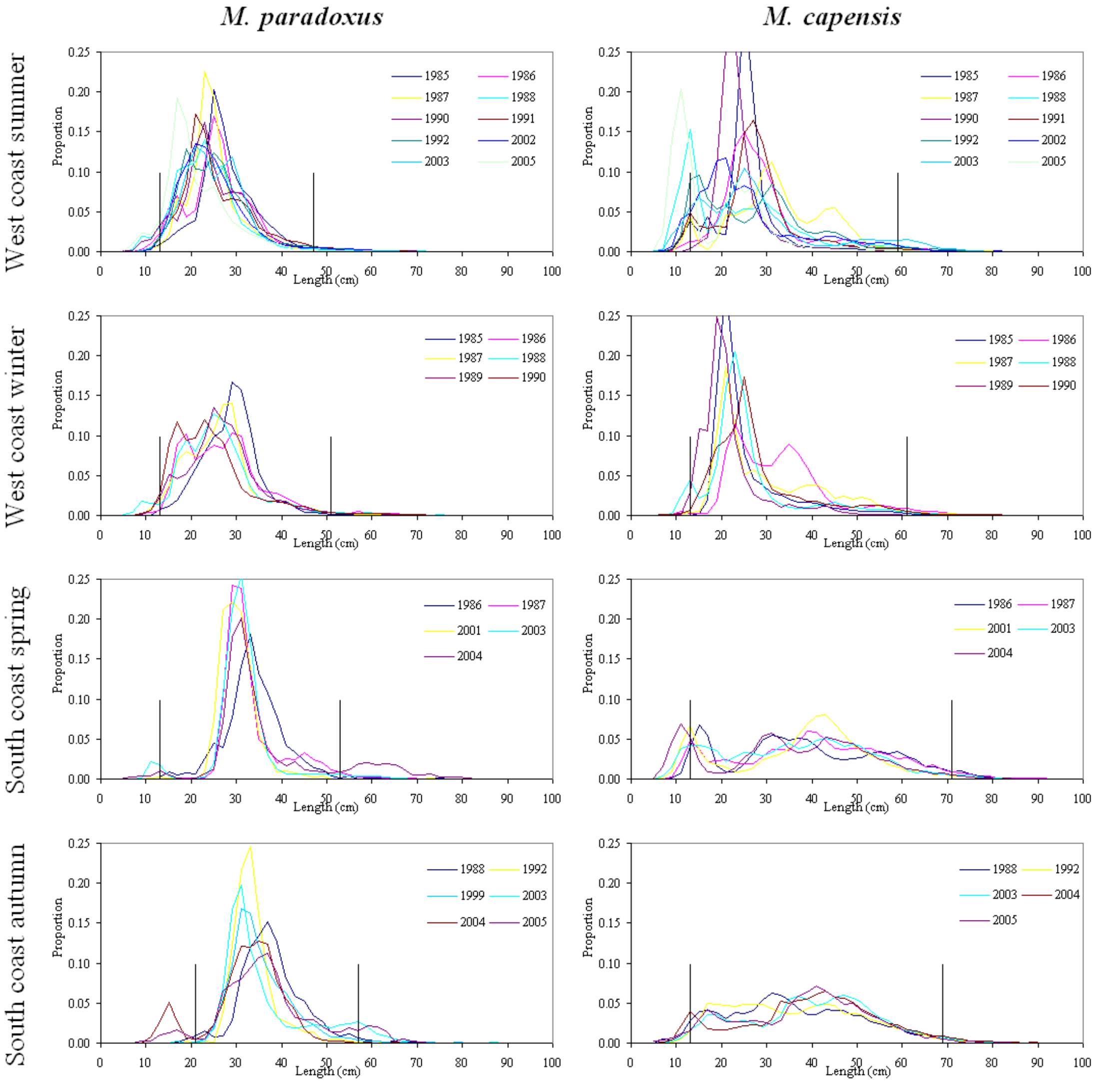


Figure App.8.I.2: Sex-aggregated survey catch-at-length information. The vertical bars show the minus and plus groups used.

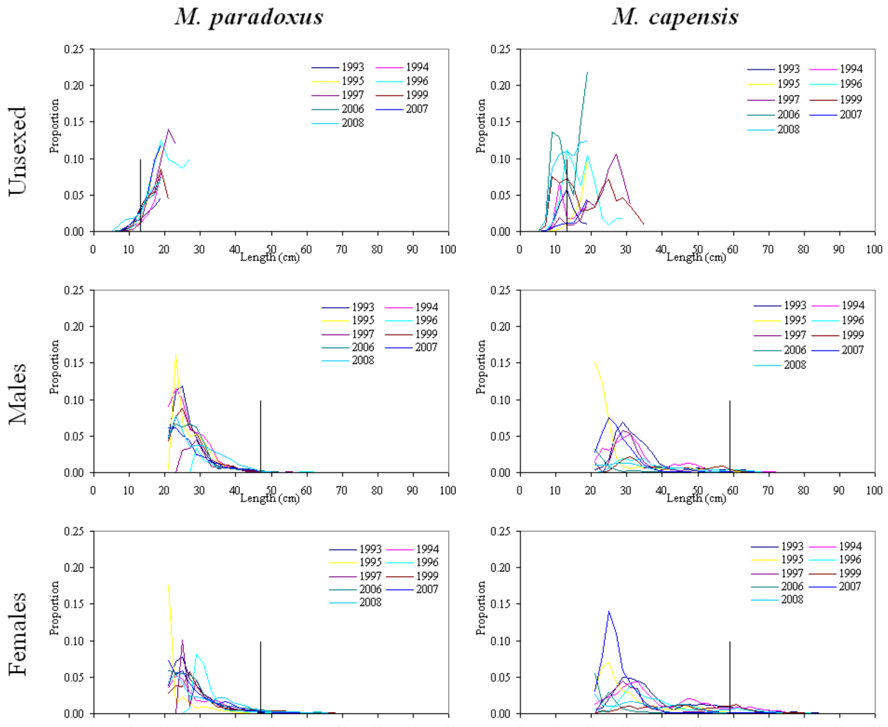


Fig App.8.I.3a: West coast summer gender-disaggregated survey catch-at-length information. The vertical bars show the minus and plus groups used.

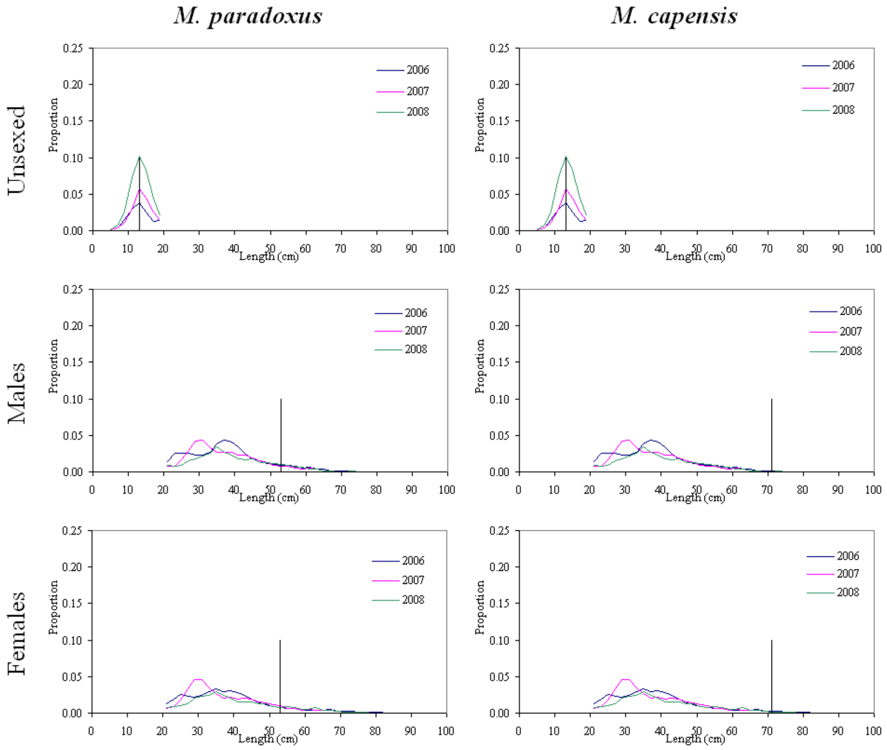


Fig App.8.I.3b: South coast spring gender-disaggregated survey catch-at-length information. The vertical bars show the minus and plus groups used.

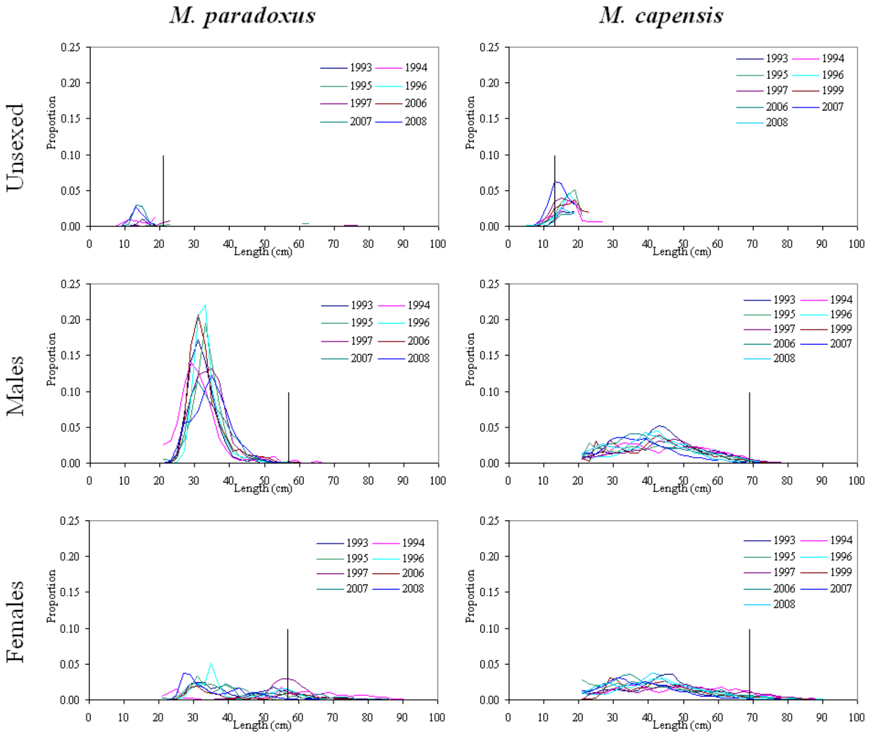


Fig App.8.I.3c: South coast autumn gender-disaggregated survey catch-at-length information. The vertical bars show the minus and plus groups used.

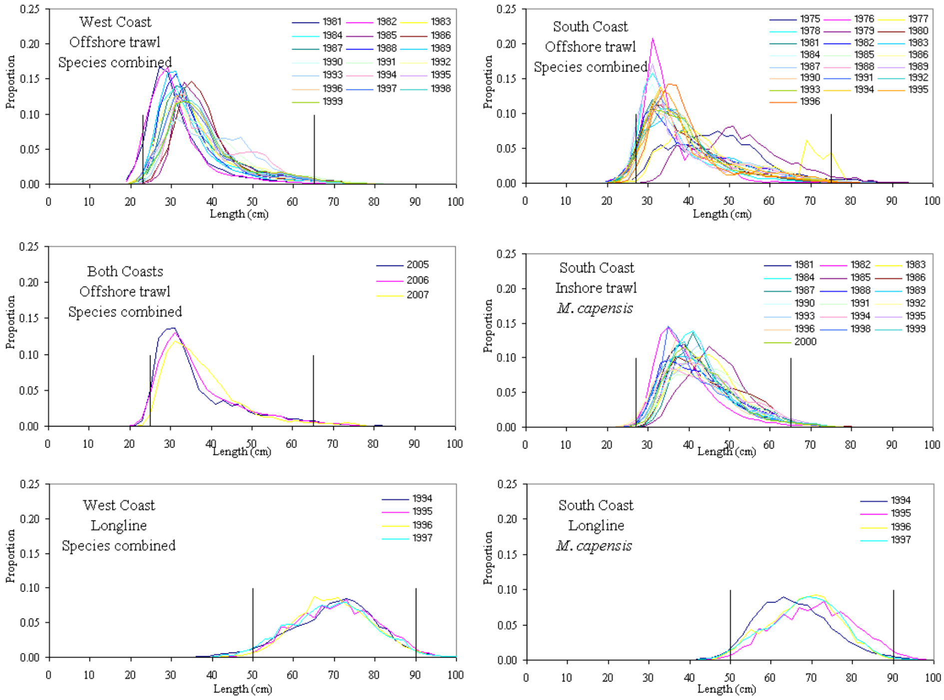
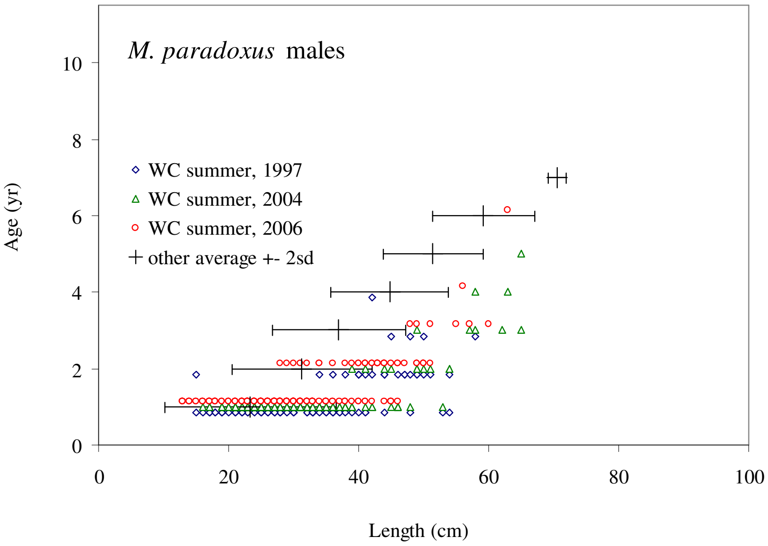


Fig App.8.I.4: Commercial catch-at-length information. The vertical bars show the minus and plus groups used.



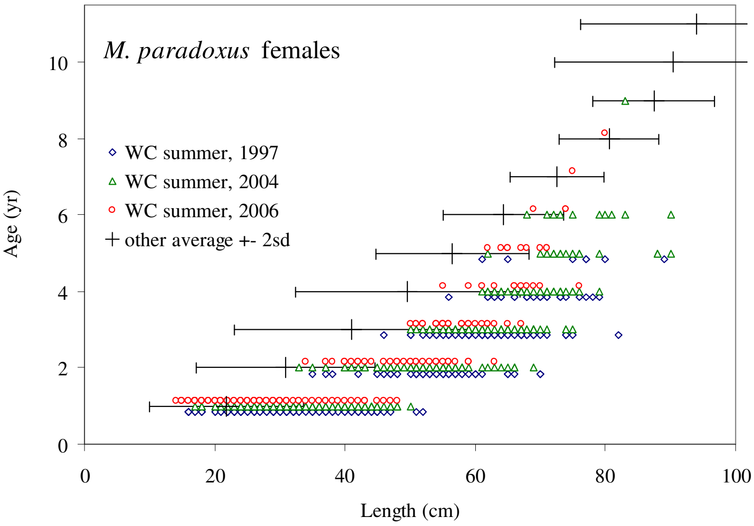


Figure App.8.I.5: Data points for each gender separately for the three *M. paradoxus* ALKs that have been omitted from the model fitting. The average of the other ALKs is shown with the error bars representing the ± 2 s.d. range.

# APPENDIX 8.II

# Gender-disaggregated, age-structured production model fitting to age-length keys

The model used is a gender-disaggregated Age-Structured Production Model (ASPM), which is fitted directly to age-length keys (ALKs) and length frequencies. The model also assesses the two species as two independent stocks and is fitted to species-disaggregated data as well as species-combined data. The general specifications and equations of the overall model are set out below, together with some key choices in the implementation of the methodology. Details of the contributions to the log-likelihood function from the different data considered are also given. Quasi-Newton minimisation is used to minimise the total negative log-likelihood function (implemented using AD Model Builder$^{\text{TM}}$, Otter Research, Ltd. (Fournier *et al.* 2011)).

## 8.II.1 Population Dynamics

### 8.II.1.1 Numbers-at-age

The resource dynamics of the two populations (*M. capensis* and *M. paradoxus*) of the South African hake are modelled by the following set of equations.

Note: for ease of reading, the 'species' subscript *s* has been omitted below where equations are identical for the two species.

$$N^{g}_{y+1,0} = R^{g}_{y+1} \qquad \text{(App.8.II.1)}$$

$$N^{g}_{y+1,a+1} = \left( N^{g}_{ya} e^{-M^{g}_{a}/2} - \sum_{f} C^{g}_{fya} \right) e^{-M^{g}_{a}/2} \qquad \text{for } 0 \le a \le m-2 \qquad \text{(App.8.II.2)}$$

$$\begin{aligned}N^g_{y+1,m} &= \left(N^g_{y,m-1}e^{-M^g_{m-1}/2} - \sum_f C^g_{f,y,m-1}\right)e^{-M^g_{m-1}/2} \\ &\quad + \left(N^g_{ym}e^{-M^g_m/2} - \sum_f C^g_{fym}\right)e^{-M^g_m/2}\end{aligned} \qquad \text{(App.8.II.3)}$$

where

$N^g_{ya}$ is the number of fish of gender *g* and age *a* at the start of year *y*[1];

$R^g_y$ is the recruitment (number of 0-year-old fish) of fish of gender *g* at the start of year *y*;

$m$ is the maximum age considered (taken to be a plus-group);

$M^g_a$ denotes the natural mortality rate on fish of gender *g* and age *a*; and

$C^g_{fya}$ is the number of hake of gender *g* and age *a* caught in year *y* by fleet *f*.

### 8.II.1.2 Recruitment

The number of recruits (i.e. new zero-year old fish) at the start of year *y* is assumed to be related to the corresponding female spawning stock size (i.e., the biomass of mature female fish). The underlying assumptions are that female spawning output can limit subsequent recruitment, but that there are always sufficient males to provide adequate fertilisation. The recruitment and corresponding female spawning stock size are related by means of the Beverton-Holt (Beverton and Holt 1957) or a modified (generalised) form of the Ricker stock-recruitment relationship. These forms are parameterized in terms of the "steepness" of the stock-recruitment relationship, $h$, the pre-exploitation equilibrium female spawning biomass, $K^{♀sp}$, and the pre-exploitation recruitment, $R_0$ and assuming a 50:50 sex-split at recruitment.

---

[1] In the interests of less cumbersome notation, subscripts have been separated by commas only when this is necessary for clarity.

$$R_y^g = \frac{4hR_0 B_y^{♀,sp}}{K^{♀,sp}(1-h)+(5h-1)B_y^{♀,sp}} e^{(\varsigma_y - \sigma_R^2/2)} \tag{App.8.II.4a}$$

for the Beverton-Holt stock-recruitment relationship and

$$R_y^g = \alpha B_y^{♀,sp} \exp\left(-\beta\left(B_y^{♀,sp}\right)^\gamma\right) e^{(\varsigma_y - \sigma_R^2/2)} \tag{App.8.II.4b}$$

with

$$\alpha = R_0 \exp\left(\beta\left(K^{♀,sp}\right)^\gamma\right) \qquad \text{and} \qquad \beta = \frac{\ln(5h)}{\left(K^{♀,sp}\right)^\gamma\left(1-5^{-\gamma}\right)}$$

for the modified Ricker relationship (for the true Ricker, $\gamma$=1) where

$\varsigma_y$ reflects fluctuation about the expected recruitment in year *y*;

$\sigma_R$ is the standard deviation of the log-residuals, which is input ($\sigma_R = 0.45$ and is taken to decrease from this value to 0.1 over the last five years to statistically stabilise estimates of recent recruitment) .

$B_y^{♀ sp}$ is the female spawning biomass at the start of year *y*, computed as:

$$B_y^{♀,sp} = \sum_{a=1}^{m} f_a^{♀} w_a^{♀} N_{ya}^{♀} \tag{App.8.II.5}$$

where

$w_a^g$ is the begin-year mass of fish of gender *g* and age *a*;

$f_a^g$ is the proportion of fish of gender *g* and age *a* that are mature (converted from maturity-at-length, see equation App.8.II.47); and

$$R_0 = K^{♀,sp} / \left[\sum_{a=1}^{m-1} f_a^{♀} w_a^{♀} e^{-\sum_{a'=0}^{a-1} M_{a'}^g} + f_m^{♀} w_m^{♀} \frac{e^{-\sum_{a'=0}^{m-1} M_{a'}^g}}{1-e^{-M_m^g}}\right] \tag{App.8.II.6}$$

For the Beverton-Holt form, *h* is bounded above by 0.98 to preclude high recruitment at extremely low spawning biomass, whereas for the modified Ricker form, *h* is bounded above by 1.5 to preclude extreme compensatory behaviour.

### 8.II.1.3 Total catch and catches-at-age

The fleet-disaggregated catch by mass, in year *y* is given by:

$$C_{fy} = \sum_{g} \sum_{a=0}^{m} \tilde{w}^{g}_{fy,a+1/2}\, C^{g}_{fya} = \sum_{g} \sum_{a=0}^{m} \tilde{w}^{g}_{fy,a+1/2}\, N^{g}_{ya} e^{-M^{g}_{a}/2} F_{fy} S^{g}_{fya} \qquad \text{(App.8.II.7)}$$

where

$C^{g}_{fya}$ is the catch-at-age, i.e. the number of fish of gender *g* and age *a*, caught in year *y* by fleet *f*;

$F_{fy}$ is the fishing mortality of a fully selected age class, for fleet *f* in year *y* (independent of *g*) ;

$$S^{g}_{fya} = \sum_{l} S^{g}_{fyl} P^{g}_{a+1/2,l} \qquad \text{(App.8.II.8)}$$

$S^{g}_{fya}$ is the commercial selectivity of gender *g* at age *a* for fleet *f* and year *y*;

$S^{g}_{fyl}$ is the commercial selectivity of gender *g* at length *l* for year *y*, and fleet *f*;

$$\tilde{w}^{g}_{fy,a+1/2} = \sum_{l} S^{g}_{fyl} w^{g}_{l} P^{g}_{a+1/2,l} \Big/ \sum_{l} S^{g}_{fyl} P^{g}_{a+1/2,l} \qquad \text{(App.8.II.9)}$$

$\tilde{w}^{g}_{fy,a+1/2}$ is the selectivity-weighted mid-year weight-at-age *a* of gender *g* for fleet *f* and year *y*;

$w^{g}_{l}$ is the weight of fish of gender *g* and length *l*;

$P^{g}_{a+1/2,l}$ is the mid-year proportion of fish of age *a* and gender *g* that fall in the length group *l* (i.e., $\sum_{l} P^{g}_{a+1/2,l} = 1$ for all ages *a*).

The matrix $P$ is calculated under the assumption that length-at-age is log-normally distributed about a mean given by the von Bertalanffy equation, i.e.:

$$\ln l_a \sim N\left[\ln\left(l_\infty\left(1-e^{-\kappa(a-t_0)}\right)\right);\left(\frac{\theta_a}{l_\infty\left(1-e^{-\kappa(a-t_0)}\right)}\right)^2\right] \qquad \text{(App.8.II.10)}$$

where $\theta_a$ is the standard deviation of length-at-age *a*, which is estimated directly in the model fitting for age 0, and for ages 1 and above a linear relationship applies:

$$\theta_a = \begin{cases} B_0 & \text{for } a = 0 \\ (\beta a + \alpha) & \text{for } 1 \le a \le m \end{cases}$$

with species and gender-specific $B_0$, $\alpha$ and $\beta$ estimated in the model fitting procedure. A penalty is added so that $\theta_a$ is increasing with age, i.e. $\beta>0$.

### 8.II.1.4 Exploitable and survey biomasses

The model estimate of the mid-year exploitable ("available") component of biomass for each species and fleet is calculated by converting the numbers-at-age into mid-year mass-at-age and applying natural and fishing mortality for half the year:

$$B^{ex}_{fy} = \sum_g \sum_{a=0}^{m} \tilde{w}^{g}_{fy,a+1/2} S^{g}_{fya} N^{g}_{ya} e^{-M^{g}_{a}/2}\left(1-\sum_f S^{g}_{fya} F_{fy} \Big/ 2\right) \qquad \text{(App.8.II.11)}$$

The model estimate of the survey biomass at the start of the year (summer) is given by:

$$B^{surv}_{y} = \sum_g \sum_{a=0}^{m_s} \tilde{w}^{g,sum}_{a} S^{g,sum}_{a} N^{g}_{ya} \qquad \text{(App. 8.II.12)}$$

and in mid-year (winter):

$$B^{surv}_{y} = \sum_g \sum_{a=0}^{m} \tilde{w}^{g,win}_{a+1/2} S^{g,win}_{a} N^{g}_{ya} e^{-M^{g}_{a}/2}\left(1-\sum_f S^{g}_{fya} F_{fy} \Big/ 2\right) \qquad \text{(App. 8.II.13)}$$

where

$S_a^{g,sum/win}$ is the survey selectivity of gender *g* for age *a,* converted from survey selectivity-at-length in the same manner as for the commercial selectivity (eqn App.II.8);

$\tilde{w}_a^{g,i}$ is the survey selectivity-weighted weight-at-age *a* of gender *g* for survey *i*, computed in the same manner as for the commercial selectivity-weight-at-age (equation App.II.9) and taking account of the begin-year ($\tilde{w}_{y,a}^{g,sum}$ from $P_{a,l}^g$) or mid-year ($\tilde{w}_{y,a+1/2}^{g,win}$ from $P_{a+1/2,l}^g$) nature of the surveys.

Note that both the spring and autumn surveys are taken to correspond to winter (mid-year).

It is assumed that the resource is at the deterministic equilibrium that corresponds to an absence of harvesting at the start of the initial year considered, i.e., $B_1^{g,sp} = K^{g,sp}$, and the year *y*=1 corresponds to 1917 when catches commence.

## 8.II.2 MSY and related quantities

The equilibrium catch for a fully selected fishing proportion *F** is calculated as:

$$C(F^*) = \sum_g \sum_a \tilde{w}_{a+1/2}^g S_a^g F^* N_a^g (F^*) e^{-\left(\left(M_a^g + S_a^g F^*\right)/2\right)} \qquad \text{(App.8.II.14)}$$

where

$S_a^g$ is the average selectivity across all fleets, for the most recent five years;

$$S_a^g = \frac{\sum_{y=2005}^{2009} \sum_f S_{fya}^g F_{fy}}{\max\left( \sum_{y=2005}^{2009} \sum_f S_{fya}^g F_{fy} \right)} \qquad \text{(App.8.II.15)}$$

where the maximum is taken over genders and ages; and with

$$N_a^g(F^*) = \begin{cases} R_1(F^*) & \text{for } a = 1 \\ N_{a-1}^g(F^*) e^{-M_{a-1}^g}\left(1 - S_{a-1}^g F^*\right) & \text{for } 1 < a < m \\ \dfrac{N_{m-1}^g(F^*) e^{-M_{m-1}^g}\left(1 - S_{m-1}^g F^*\right)}{\left(1 - e^{-M_m^g}\left(1 - S_m^g F^*\right)\right)} & \text{for } a = m \end{cases} \qquad \text{(App.8.II.16)}$$

where

$$R_1(F^*) = \frac{\alpha B^{♀,sp}(F^*)}{\beta + B^{♀,sp}(F^*)} \qquad \text{(App.8.II.17)}$$

for a Beverton-Holt stock–recruitment relationship.

The maximum of $C(F^*)$ is then found by searching over $F^*$ to give $F^*_{\text{MSY}}$, with the associated female spawning biomass given by:

$$B_{MSY}^{♀,sp} = \sum_a f_a^{♀} w_a^{♀} N_a^{♀}\left(F^*_{\text{MSY}}\right)$$

## 8.II.3 The likelihood function

The model is fit to CPUE and survey biomass indices, commercial and survey length frequencies, survey age-length keys, as well as to the stock-recruitment curve to estimate model parameters. Contributions by each of these to the negative of the log-likelihood ($-\ell\text{n}L$) are as follows[2].

### 8.II.3.1 CPUE relative biomass data

The likelihood is calculated by assuming that the observed biomass index (here CPUE) is log-normally distributed about its expected value:

$$I_y^i = \hat{I}_y^i e^{\varepsilon_y^i} \quad \text{or} \quad \varepsilon_y^i = \ell\text{n}\left(I_y^i\right) - \ell\text{n}\left(\hat{I}_y^i\right) \qquad \text{(App.8.II.18)}$$

---

[2] Strictly it is a penalised log-likelihood which is maximised in the fitting process, as some contributions that would correspond to priors in a Bayesian estimation process are added.

where

$I_y^i$ is the biomass index for year *y* and series *i* (which corresponds to a specified species and fleet);

$\hat{I}_y^i = \hat{q}^i \hat{B}_{fy}^{ex}$ is the corresponding model estimate, where $\widehat{B}_{fy}^{ex}$ is the model estimate of exploitable resource biomass, given by equation App.8.II.11;

$\hat{q}^i$ is the constant of proportionality for biomass series *I*; and

$\varepsilon_y^i$ from $N\left(0,\left(\sigma_y^i\right)^2\right)$.

In cases where the CPUE series are based upon species-aggregated catches (as available pre-1978), the corresponding model estimate is derived by assuming two types of fishing zones: z1) an "*M. capensis* only zone", corresponding to shallow-water and z2) a "mixed zone" (Figure App.8.II.1).

The total catch of hake of both species (*BS*) by fleet *f* in year *y* ($C_{BS,fy}$) can be written as:

$$C_{BS,fy} = C_{C,fy}^{z1} + C_{C,fy}^{z2} + C_{P,fy} \qquad \text{(App.8.II.19)}$$

where

$C_{C,fy}^{z1}$ is the *M. capensis* catch by fleet *f* in year *y* in the *M. capensis* only zone (z1);

$C_{C,fy}^{z2}$ is the *M. capensis* catch by fleet *f* in year *y* in the mixed zone (z2); and

$C_{P,fy}$ is the *M. paradoxus* catch by fleet *f* in year *y* in the mixed zone.

Catch rate is assumed to be proportional to exploitable biomass. Furthermore, let $\gamma$ be the proportion of the *M. capensis* exploitable biomass in the mixed zone ($\gamma = B_{C,fy}^{ex,z2} / B_{C,fy}^{ex}$) (assumed to be constant throughout the period for simplicity) and $\psi_{fy}$ be the proportion of the effort of fleet *f* in the mixed zone in year *y* ($\psi_{fy} = E_{fy}^{z2} / E_{fy}$), so that:

$$C^{z1}_{C,fy} = q^{i,z1}_{C} B^{ex,z1}_{Cfy} E^{z1}_{fy} = q^{i,z1}_{C}(1-\gamma)B^{ex}_{C,fy}\left(1-\psi_{fy}\right)E_{fy} \qquad \text{(App.8.II.20)}$$

$$C^{z2}_{C,fy} = q^{i,z2}_{C} B^{ex,z2}_{C,fy} E^{z2}_{fy} = q^{i,z2}_{C}\gamma B^{ex}_{C,fy}\psi_{fy}E_{fy} \text{ and} \qquad \text{(App.8.II.21)}$$

$$C_{P,fy} = q^{i}_{P} B^{ex}_{P,fy} E^{z2}_{fy} = q^{i}_{P} B^{ex}_{P,fy}\psi_{fy}E_{fy} \qquad \text{(App.8.II.22)}$$

where

$E_{fy} = E^{z1}_{fy} + E^{z2}_{fy}$ is the total effort of fleet *f*, corresponding to combined-species CPUE series *i* which consists of the effort in the *M. capensis* only zone ($E^{z1}_{fy}$) and the effort in the mixed zone ($E^{z2}_{fy}$);

$q^{i,zj}_{C}$ is the catchability for *M. capensis* (*C*) for biomass series *i*, and zone *zj*; and

$q^{i}_{P}$ is the catchability for *M. paradoxus* (*P*) for biomass series *i*.

It follows that:

$$C_{C,fy} = B^{ex}_{C,fy} E_{fy}\left[q^{i,z1}_{C}(1-\gamma)\left(1-\psi_{fy}\right) + q^{i,z2}_{C}\gamma\psi_{fy}\right] \qquad \text{(App.8.II.23)}$$

$$C_{P,fy} = B^{ex}_{P,fy} E_{fy} q^{i}_{P}\psi_{fy} \qquad \text{(App.8.II.24)}$$

From solving equations App.8.II.23 and App.8.II.24:

$$s_{fy} = \frac{q^{i,z1}_{C}(1-\gamma)}{\left\{\dfrac{C_{C,fy}B^{ex}_{P,fy}q^{i}_{P}}{B^{ex}_{C,fy}C_{P,fy}} - q^{i,z2}_{C}\gamma + q^{i,z1}_{C}(1-\gamma)\right\}} \qquad \text{(App.8.II.25)}$$

and:

$$\hat{I}^{i}_{y} = \frac{C_{fy}}{E_{fy}} = \frac{C_{fy}B^{ex}_{P,fy}q^{i}_{P}\psi_{fy}}{C_{P,fy}} \qquad \text{(App.8.II.26)}$$

| Zone 1 (z1):<br>*M. capensis* only | Zone 2 (z2):<br>Mixed zone |
|---|---|
| *M. capensis*:<br>biomass ($B_C^{z1}$), catch($C_C^{z1}$)<br>Effort in zone 1 ($E^{z1}$) | *M. capensis*:<br>biomass ($B_C^{z2}$), catch($C_C^{z2}$)<br>*M. paradoxus*:<br>biomass ($B_P$), catch($C_P$)<br>Effort in zone 2 ($E^{z2}$) |

Figure App.8.II.1: Diagrammatic representation of the two conceptual fishing zones.

Two species-aggregated CPUE indices are available: the ICSEAF West Coast and the ICSEAF South Coast series. For consistency, *q*'s for each species (and zone) are forced to be in the same proportion:

$$q_s^{SC} = rq_s^{WC} \qquad \text{(App.8.II.27)}$$

To correct for possible negative bias in estimates of variance $(\sigma_y^i)$ and to avoid according unrealistically high precision (and so giving inappropriately high weight) to the CPUE data, lower bounds on the standard deviations of the residuals for the logarithm of the CPUE series have been enforced: for the historic ICSEAF CPUE series (separate West Coast and South Coast series) the lower bound is set to 0.25, and to 0.15 for the recent GLM-standardised CPUE series, i.e.: $\sigma^{ICSEAF} \geq 0.25$ and $\sigma^{GLM} \geq 0.15$.

The contribution of the CPUE data to the negative of the log-likelihood function (after removal of constants) is then given by:

$$-\ell n\, L^{CPUE} = \sum_i \sum_y \left[ \ell n \left(\sigma_y^i\right) + \left(\varepsilon_y^i\right)^2 / 2\left(\sigma_y^i\right)^2 \right] \qquad \text{(App.8.II.28)}$$

where

$\sigma_y^i$ is the standard deviation of the residuals for the logarithms of index *i* in year *y*.

Homoscedasticity of residuals for CPUE series is customarily assumed[3], so that $\sigma^i_y = \sigma^i$ is estimated in the fitting procedure by its maximum likelihood value:

$$\hat{\sigma}^i = \sqrt{1/n_i \sum_y \left(\ell n(I^i_y) - \ell n(\hat{I}^i_y)\right)^2} \qquad \text{(App.8.II.29)}$$

where $n_i$ is the number of data points for biomass index *i*.

In the case of the species-disaggregated CPUE series, the catchability coefficient $q^i$ for biomass index *i* is estimated by its maximum likelihood value, which in the more general case of heteroscedastic residuals is given by:

$$\ln \hat{q}^i = \frac{\sum_y \left(\ln I^i_y - \ln \hat{B}^{ex}_{fy}\right) / \left(\sigma^i_y\right)^2}{\sum_y 1/\left(\sigma^i_y\right)^2} \qquad \text{(App.8.II.30)}$$

In the case of the species-combined CPUE, $q_C^{WC,z1}$, $q_C^{WC,z2}$, $q_P^{WC}$, *r* and $\gamma$ are estimated directly in the fitting procedure.

### 8.II.3.2 Survey biomass data

Data from the research surveys are treated as relative biomass indices in a similar manner to the species-disaggregated CPUE series above, with survey selectivity function $S_a^{g,sum/win}$ replacing the commercial selectivity $S^g_{fya}$ (see equations App.8.II.12 and App.8.II.13 above, which also take account of the begin- or mid-year nature of the survey).

An estimate of sampling variance is available for most surveys and the associated $\sigma^i_y$ is generally taken to be given by the corresponding survey CV. However, these estimates likely fail to include all sources of variability, and unrealistically high precision (low variance and hence high weight) could hence be accorded to these indices. The contribution of the survey data to the negative log-likelihood is of the same form as that of the CPUE biomass data (see equation App.8.II.28). The procedure adopted takes into

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[3] There are insufficient data in any series to enable this to be tested with meaningful power.

account an additional variance $(\sigma_A)^2$ which is treated as another estimable parameter in the minimisation process. This procedure is carried out enforcing the constraint that $(\sigma_A)^2 > 0$, i.e. the overall variance cannot be less than its externally input component.

In June 2003, the trawl gear on the *Africana* was changed and a different value for the multiplicative bias factor *q* is taken to apply to the surveys conducted with the new gear. Calibration experiments have been conducted between the *Africana* with the old gear (hereafter referred to as the "old *Africana*") and the *Nansen*, and between the *Africana* with the new gear ("new *Africana*") and the *Nansen*, in order to provide a basis to relate the multiplicative biases of the *Africana* with the two types of gear ($q_{old}$ and $q_{new}$). A GLM analysis assuming negative binomial distributions for the catches made (Brandão *et al.*, 2004) provided the following estimates:

$\Delta \ell n q^{capensis} = -0.494$ with $\sigma_{\Delta \ell n q^{capensis}} = 0.141$ i.e. $\left(q^{new}/q^{old}\right)^{capensis} = 0.610$ and

$\Delta \ell n q^{paradoxus} = -0.053$ with $\sigma_{\Delta \ell n q^{paradoxus}} = 0.117$ i.e. $\left(q^{new}/q^{old}\right)^{paradoxus} = 0.948$

where

$$\ell n q^s_{new} = \ell n q^s_{old} + \Delta \ell n q^s \quad \text{with } s = \textit{capensis} \text{ or } \textit{paradoxus} \qquad \text{(App.8.II.31)}$$

No plausible explanation has yet been found for the particularly large extent to which catch efficiency for *M. capensis* is estimated to have decreased for the new research survey trawl net. It was therefore recommended (BENEFIT 2004) that the ratio of the catchability of the new to the previous *Africana* net be below 1, but not as low as the ratio estimated from the calibration experiments. $\Delta \ell n q^{capensis}$ is therefore taken as -0.223, i.e. $\left(q^{new}/q^{old}\right)^{capensis} = 0.8$.

The following contribution is therefore added as a penalty (or a log prior in a Bayesian context) to the negative log-likelihood in the assessment:

$$-\ell n L^{q-ch} = \left(\ell n q_{new} - \ell n q_{old} - \Delta \ell n q\right)^2 / 2\sigma^2_{\Delta \ell n q} \qquad \text{(App.8.II.32)}$$

A different length-specific selectivity is estimated for the "old *Africana*" and the "new *Africana*".

The survey's coefficients of catchability $q$ (for the survey with the old *Africana* gear) are constrained to values below 1 (i.e. it is assumed that the nets do not herd the hake):

$$pen^q = \sum_i \left(q^i_{old} - 1\right)^2 \Big/ 0.02^2 \quad \text{if} \qquad q^i_{old} > 1 \qquad \text{(App.8.II.33)}$$

### 8.II.3.3 Commercial proportions at length

Commercial proportions at length cannot be disaggregated by species and gender. The model is therefore fit to the proportions at length as determined for both species and gender combined.

The catches at length are computed as:

$$C_{fyl} = \sum_s \sum_g \sum_{a=0}^{m} N^g_{sya} F_{sfy} S^g_{sfyl} P^g_{s,a+1/2,l} e^{-M^g_{sa}/2} \left( 1 - \sum_f S^g_{sfya} F_{fy} \Big/ 2 \right) \qquad \text{(App.8.II.34)}$$

with the predicted proportions at length:

$$\widehat{p}^i_{yl} = C_{fyl} \Big/ \sum_{l'} C_{fyl'} \qquad \text{(App.8.II.35)}$$

The contribution of the proportion at length data to the negative of the log-likelihood function when assuming an "adjusted" lognormal error distribution is given by:

$$-\ell\text{n}\, L^{\text{length}} = 0.1 \sum_y \sum_l \left\lfloor \ell n \left( \sigma^i_{len} / \sqrt{p^i_{yl}} \right) + p^i_{yl} \left( \ell n p^i_{yl} - \ell n\, \hat{p}^i_{yl} \right)^2 / 2 \left( \sigma^i_{len} \right)^2 \right\rfloor \qquad \text{(App.8.II.36)}$$

where

the superscript '*i*' refers to a particular series of proportions at length data which reflect a specified fleet, and species (or combination thereof); and

$\sigma^i_{len}$ is the standard deviation associated with the proportion at length data, which is estimated in the fitting procedure by:

$$\hat{\sigma}^{i}_{len} = \sqrt{\sum_y \sum_l p^{i}_{yl} \left( \ln p^{i}_{yl} - \ln \hat{p}^{i}_{yl} \right)^2 / \sum_y \sum_l 1} \qquad \text{(App.8.II.37)}$$

The initial 0.1 multiplicative factor is a somewhat arbitrary downweighting to allow for correlation between proportions in adjacent length groups. The coarse basis for this adjustment is the ratio of effective number of age-classes present to the number of length groups in the minimisation, under the argument that independence in variability is likely to be more closely related to the former.

Commercial proportions at length are incorporated in the likelihood function using equation App.8.II.36, for which the summation over length $l$ is taken from length $l_{minus}$ (considered as a minus group) to $l_{plus}$ (a plus group). The length for the minus- and plus-groups are fleet specific and are chosen so that typically a few percent, but no more, of the fish sampled fall into these two groups.

### 8.II.3.4 Survey proportions at length

The survey proportions at length are incorporated into the negative of the log-likelihood in an analogous manner to the commercial catches-at-age, assuming an adjusted log-normal error distribution (equation App.8.II.36). In this case however, data are disaggregated by species, and for some surveys further disaggregated by gender:

$p^{g,surv}_{syl} = \dfrac{C^{g,surv}_{syl}}{\sum_g \sum_{l'} C^{g,surv}_{syl'}}$ is the observed proportion of fish of species *s*, gender *g* and length *l* from survey *surv* in year *y*; and

$\hat{p}^{g,surv}_{syl}$ is the expected proportion of fish of species *s*, gender *g* and length *l* in year *y* in the survey *surv*, given by:

$$\hat{p}^{g,surv}_{syl} = \frac{\sum_a S^{g,sum}_{sl} P^{g}_{sal} N^{g}_{sya}}{\sum_g \sum_{l'} \sum_a S^{g,sum}_{sl'} P^{g}_{sal'} N^{g}_{sya}} \qquad \text{(App.8.II.38)}$$

for begin-year (summer) surveys, or

$$\hat{p}^{g,surv}_{syl} = \frac{\sum_a S^{g,win}_{sl} P^g_{s,a+1/2,l} N^g_{sya} e^{-M^g_{sa}/2}\left(1-\sum_f S^g_{sfya}F_{sfy}\Big/2\right)}{\sum_g\sum_{l'}\sum_a S^{g,win}_{sl'} P^g_{s,a+1/2,l'} N^g_{sya} e^{-M^g_{sa}/2}\left(1-\sum_f S^g_{sfya}F_{sfy}\Big/2\right)} \qquad \text{(App.8.II.39)}$$

for mid-year (autumn, winter or spring) surveys.

### 8.II.3.5 Age-length keys

Under the assumption that fish are sampled randomly with respect to age within each length-class, the contribution to the negative log-likelihood for the ALK data (ignoring constants) is:

$$-\ln L^{ALK} = -w\sum_i\sum_l\sum_a\left[A^{obs}_{i,l,a}\ln\left(\hat{A}_{i,l,a}\right) - A^{obs}_{i,l,a}\ln\left(A^{obs}_{i,l,a}\right)\right] \qquad \text{(App.8.II.40)}$$

where

$w$ is a downweighting factor to allow for overdispersion in these data compared to the expectation for a multinomial distribution with independent data; this weight factor is somewhat arbitrarily set to 0.01 to avoid these data overriding trend information in the indices of biomass;

$A^{obs}_{i,a,l}$ is the observed number of fish of size class $l$ that fall in age $a$, for ALK $i$ (a specific combination of survey, year, species and gender);

$\hat{A}_{i,a,l}$ is the model estimate of $A^{obs}_{i,a,l}$, computed as:

$$\hat{A}_{i,a,l} = W_{i,l}\frac{C_{i,a,l}\tilde{A}_{a,l}}{\sum_{a'} C_{i,a',l}\tilde{A}_{a',l}} \qquad \text{(App.8.II.41)}$$

where

$W_{i,l}$ is the number of fish in length class $l$ that were aged for ALK $i$,

$\tilde{A}_{a,l} = \sum_{a} P(a'|a)A_{a,l}$ is the ALK for age *a* and length *l* after accounting for age-reading error,

with $P(a'|a)$, the age-reading error matrix, representing the probability of an animal of true age *a* being aged to be that age or some other age *a*'.

Age-reading error matrices have been computed for each reader and for each species as reported in Appendix 8.III.

When multiple readers age the same fish, these data are considered to be independent information in the model fitting.

### 8.II.3.6 Stock-recruitment function residuals

The stock-recruitment residuals are assumed to be log-normally distributed. Thus, the contribution of the recruitment residuals to the negative of the log-likelihood function is given by:

$$-\ell nL^{SR} = \sum_{s}\left[\sum_{y=y1}^{y2} {\varsigma_{sy}}^{2} \Big/ 2\sigma_R^2 + \left(\sum_{y=y1}^{y2} \varsigma_{sy}\right)^2 \Big/ 0.01^2\right] \qquad \text{(App.8.II.42)}$$

where

$\varsigma_{sy}$ is the recruitment residual for species *s*, and year *y*, which is assumed to be log-normally distributed with standard deviation $\sigma_R$ and which is estimated for year *y1* to *y2* (see equation App.8.II.4) (estimating the stock-recruitment residuals is made possible by the availability of catch-at-age data, which give some indication of the age-structure of the population); and

$\sigma_R$ is the standard deviation of the log-residuals, which is input.

The stock-recruitment residuals are estimated for years 1985 to 2006, with recruitment for other years being set deterministically (i.e. exactly as given by the estimated stock-recruitment curve) as there is insufficient catch-at-age information to allow reliable residual estimation for earlier years. A limit on the recent recruitment fluctuations is set by having the $\sigma_R$ (which measures the extent of variability in recruitment – see equation – App.II.42) decreasing linearly from 0.45 in 2004 to 0.1 in 2009, effectively forcing recruitment over the last years to lie closer to the stock-recruitment relationship curve.

The second term on the right hand side is introduced to force the average of the residuals estimated over the period from *y1* to *y2* to be close to zero, for reasons elaborated in the main text.

## 8.II.4 Model parameters

### 8.II.4.1 Estimable parameters

The primary parameters estimated are the species-specific female virgin spawning biomass $\left(K_s^{\female sp}\right)$ and "steepness" of the stock-recruitment relationship ($h_s$). The standard deviations $\sigma^i$ for the CPUE series residuals (the species-combined as well as the GLM-standardised series) as well as the additional variance $\left(\sigma_A^i\right)^2$ for each survey biomass series are treated as estimable parameters in the minimisation process. Similarly, in the case of the species-combined CPUE, $q_C^{WC,z1}$, $q_C^{WC,z2}$, $q_P^{WC}$, $r$ and $\gamma$ are directly estimated in the fitting procedure.

The species- and gender-specific von Bertalanffy growth curve parameters ($l_\infty$, $\kappa$ and $t_0$) are estimated directly in the model fitting process, as well as $B_0$, $\alpha$ and $\beta$, values used to compute the standard deviation of the length-at-age *a*.

The following parameters are also estimated in the model fits undertaken (if not specifically indicated as fixed):

*8.II.4.1.1 Natural mortality:*

Natural mortality ($M_{sa}^{g}$) is assumed to be age-specific and is calculated using the following functional form (the selection of the specific form here is based on convenience and is somewhat arbitrary):

$$M_{sa}^{♀} = \begin{cases} M_{s2}^{♀} & \text{for} \quad a \le 1 \\ \alpha_s^M + \dfrac{\beta_s^M}{a+1} & \text{for} \quad 2 \le a \le 5 \\ M_{s5}^{♀} & \text{for} \quad a > 5 \end{cases} \qquad \text{(App.8.II.43)}$$

and

$$M_{sa}^{males} = \upsilon^s M_{sa}^{females} \qquad \text{(App.8.II.44)}$$

$M_{s0}$ and $M_{s1}$ are set equal to $M_{s2}$ $(= \alpha_s^M + \beta_s^M/3)$ as there are no data (hake of ages younger than 2 are rare in catch and survey data) which would allow independent estimation of $M_{s0}$ and $M_{s1}$.

When *M* values are estimated in the fit, a penalty is added to the total –lnL so that $M_{s2} \ge M_{s5}$:

$$pen^M = \sum_s (M_{s5} - M_{s2})^2 / 0.01^2 \qquad \text{if } M_{s2} < M_{s5} \qquad \text{(App.8.II.45)}$$

*8.II.4.1.2 Stock-recruitment residuals:*

Stock-recruitment residuals $\varsigma_{sy}$ are estimable parameters in the model fitting process. They are estimated separately for each species from 1985 to the present, and set to zero pre-1985 because there are no catch-at-length data for that period to provide the information necessary to inform estimation.

Table App.8.II.1 summarises the estimable parameters, excluding the selectivity parameters.

*8.II.4.1.3 Survey fishing selectivity-at-length:*

The survey selectivities are estimated directly for seven pre-determined lengths for *M. paradoxus* and *M. capensis*. When the model was fitted to proportion-at-age rather than proportion-at-length, survey selectivities were estimated directly for each age (i.e. seven age classes). The lengths at which selectivity is estimated directly are survey specific (at constant intervals between the minus and plus groups) and are given in Table App.8.II.2. Between these lengths, selectivity is assumed to change linearly. The slope from lengths $l_{minus}$ to $l_{minus}$+1 is assumed to continue exponentially to lower lengths down to length *1*, and similarly the slope from lengths $l_{plus}$-1 to $l_{plus}$ for *M. paradoxus* and *M. capensis* to continue for greater lengths.

For the South Coast spring and autumn surveys, gender-specific selectivities are estimated for *M. paradoxus*. Furthermore, the female selectivities are scaled down by a parameter estimated for each of these two surveys to allow for the male predominance in the survey catch.

A penalty is added to the total –lnL to smooth the selectivities to smooth the selectivities by penalising deviations from straight line dependence (the choice of a weighting of 3 was made empirically to balance this term having sufficient but not undue influence) :

$$pen^{survS} = \sum_{i} \sum_{L=L_1+1}^{L_7-1} 3\left(S_{L-1}^{i} - 2S_{L}^{i} + S_{L+1}^{i}\right)^2 \qquad \text{(App.8.II.46)}$$

where *i* is a combination of survey, species and gender.

*8.II.4.1.4 Commercial fishing selectivity-at-length:*

The fishing selectivity-at-length (gender independent) for each species and fleet, $S_{sfl}$, is estimated in terms of a logistic curve given by:

$$S_{sfl} = \left[1 + \exp\left(-\left(l - l_{sf}^{c}\right)/\delta_{sf}^{c}\right)\right]^{-1} \qquad \text{(App.8.II.47)}$$

where

$l_{sf}^{c}$ cm is the length-at-50% selectivity,

$\delta^c_{sf}$ cm$^{-1}$ defines the steepness of the ascending limb of the selectivity curve.

The selectivity is sometimes modified to include a decrease in selectivity at larger lengths, as follows:

$$S_{sfl} = S_{s,f,l-1}e^{-s_{sfl}} \qquad \text{for } l > l_{slope}, \qquad \text{(App.8.II.48)}$$

where

$s_{sfl}$ measures the rate of decrease in selectivity with length for fish longer than $l_{slope}$ for the fleet concerned, and is referred to as the "selectivity slope"; and

$l_{slope}$ is fixed externally from the model, values for each fleet and species are given in Table App.8.II.2.

Periods of fixed and changing selectivity have been assumed for the offshore trawl fleet to take account of the change in the selectivity at low ages over time in the commercial catches, likely due to the phasing out of the (illegal) use of net liners to enhance catch rates.

On the South Coast, for *M. paradoxus*, the female offshore trawl selectivity (only the trawl fleet is assumed to catch *M. paradoxus* on the South Coast) is scaled down by a factor taken as the average of those estimated for the South Coast spring and autumn surveys. Although there is no gender information for the commercial catches, the South Coast spring and autumn surveys catch a much higher proportion of male *M. paradoxus* than female (ratios of about 7:1 and 3.5:1 for spring and autumn respectively). This is assumed to reflect a difference in distribution of the two genders which would therefore affect the commercial fleet similarly.

Details of the fishing selectivities (including the number of parameters estimated) that are used in the assessment are shown in Table App.8.II.4.

## 8.II.4.2 Input parameters and other choice for application to hake

### *8.II.4.2.1 Age-at-maturity:*

The proportion of fish of species *s*, gender *g* and length *l* that are mature is assumed to follow a logistic curve with the parameter values given below (from Fairweather and Leslie 2008, "stage 2, >40cm" for females and Fairweather, pers. commn for males):

Table App.8.II.1: Maturity-at-length logistic curve parameter values.

| | $l_{50}$ (cm) | N |
|---|---|---|
| *M. paradoxus*: | | |
| Males | 28.63 | 5.07 |
| Females | 42.24 | 4.46 |
| *M. capensis*: | | |
| Males | 34.35 | 7.38 |
| Females | 40.80 | 7.51 |

Maturity-at-length is then converted to maturity-at-age as follows:

$$f_{sa}^{g}=\sum_{l} f_{sl}^{g} P_{a,l}^{g} \qquad \text{(App.8.II.49)}$$

*8.II.4.2.2 Weight-at-length:*

The weight-at-length for each species and gender is calculated from the mass-at-length function, with values of the parameters for this function listed below (from Fairweather 2008, taking the average of the West and South coasts):

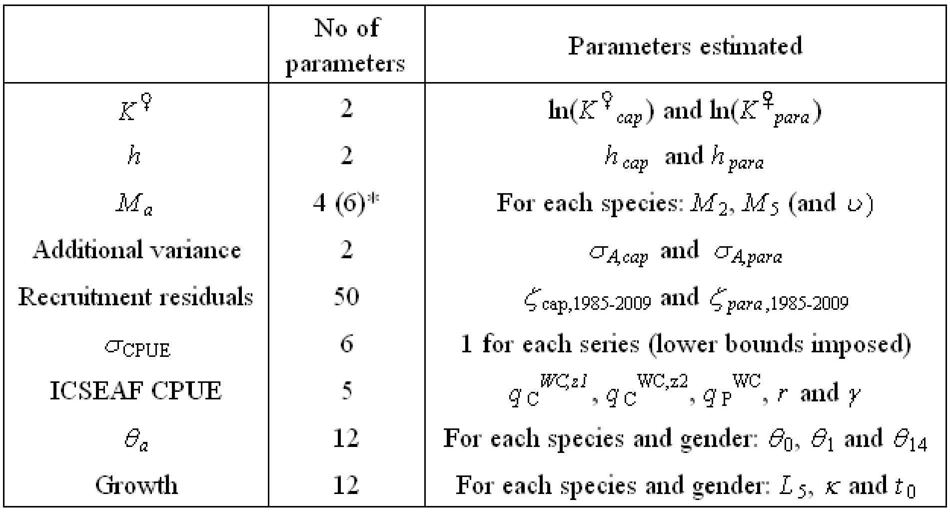
Table App.8.II.2: Weight-at-length parameter values.

| | $\perp$ (gm/cm$^{\perp}$) | $\perp$ |
|---|---|---|
| *M. paradoxus*: | | |
| Males | 0.007541 | 2.988 |
| Females | 0.005836 | 3.065 |
| *M. capensis*: | | |
| Males | 0.006307 | 3.061 |
| Females | 0.005786 | 3.085 |

*8.II.4.2.3 Minus- and plus-groups*

Because of a combination of gear selectivity and mortality, a relatively small number of fish in the smallest and largest length classes are caught. In consequence, there can be relatively larger errors (in terms of variance) associated with these data. To reduce this effect, the assessment is conducted with minus- and plus-groups obtained by summing the data over the lengths below and above $l_{minus}$ and $l_{plus}$ respectively. The minus- and plus-group used are given in Table App.8.II.5 (and plotted in Figures.8.I.2 and 3). Furthermore, the proportions at length data (both commercial and survey) are summed into 2cm length classes for the model fitting.

Table App.8.II.1: Parameters estimated in the model fitting procedure, excluding selectivity parameters.



| | No of parameters | Parameters estimated |
|---|---|---|
| $K^{♀}$ | 2 | $\ln(K^{♀}_{cap})$ and $\ln(K^{♀}_{para})$ |
| $h$ | 2 | $h_{cap}$ and $h_{para}$ |
| $M_a$ | 4 (6)* | For each species: $M_2$, $M_5$ (and $\upsilon$) |
| Additional variance | 2 | $\sigma_{A,cap}$ and $\sigma_{A,para}$ |
| Recruitment residuals | 50 | $\zeta_{\text{cap},1985\text{-}2009}$ and $\zeta_{para,1985\text{-}2009}$ |
| $\sigma_{\text{CPUE}}$ | 6 | 1 for each series (lower bounds imposed) |
| ICSEAF CPUE | 5 | $q_{\text{C}}^{WC,z1}$, $q_{\text{C}}^{\text{WC,z2}}$, $q_{\text{P}}^{\text{WC}}$, $r$ and $\gamma$ |
| $\theta_a$ | 12 | For each species and gender: $\theta_0$, $\theta_1$ and $\theta_{14}$ |
| Growth | 12 | For each species and gender: $L_5$, $\kappa$ and $t_0$ |

* if not fixed on input

Table App.8.II.2: Lengths (in cm) at which survey selectivity is estimated directly.

| | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|
| *M. paradoxus* | West coast summer | 13 | 18 | 23 | 28 | 32 | 37 | 42 | 47 |
| | West coast winter | 13 | 18 | 24 | 29 | 35 | 40 | 46 | 51 |
| | South coast spring | 21 | 26 | 30 | 35 | 39 | 44 | 48 | 53 |
| | South coast autumn | 21 | 26 | 31 | 36 | 42 | 47 | 52 | 65 |
| *M. capensis* | West coast summer | 13 | 20 | 26 | 33 | 39 | 46 | 52 | 59 |
| | West coast winter | 13 | 17 | 21 | 30 | 40 | 47 | 54 | 61 |
| | South coast spring | 13 | 19 | 28 | 38 | 46 | 54 | 63 | 71 |
| | South coast autumn | 13 | 19 | 28 | 36 | 44 | 52 | 61 | 69 |

Table App.8.II.3: Length (cm) at which selectivity starts to decrease ($l_{slope}$) for each species and fleet.

| | *M. paradoxus* | *M. capensis* |
|---|---|---|
| WC offshore trawl | 40 | 70 |
| SC offshore trawl | 70 | 70 |
| SC inshore trawl | - | 55 |
| WC longline | 85 | 85 |
| SC longline | - | 85 |
| SC handline | - | 70 |

Table App.8.II.4: Details for the commercial selectivity-at-length for each fleet and species combination, as well as indications of what data are available.

| | *M. paradoxus* | | *M. capensis* | | data available |
|---|---|---|---|---|---|
| | No of est. parameters | Comments | No of est. parameters | Comments | |
| 1. West coast offshore | | | | | |
| 1917-1976 | 0 | set equal to 1989 | 0 | set equal to 1989 | |
| 1977-1984 | 3 | two logistic parameters estimated (same slope as 1993+) | 0 | differential shift compared to 1993+ as for paradoxus, slope 1/3 of inshore | species combined |
| 1985-1992 | 0 | linear change between 1984 and 1993 selectivity | 0 | linear change between 1984 and 1993 selectivity | species combined |
| 1993-2009 | 2 | two logistic + slope parameters estimated | 0 | same as SC inshore but shifted to the right by 5 cm, slope 1/3 of inshore | species combined |
| 2. South coast offshore | | | | | |
| 1917-1976 | 0 | set equal to 1989 | 0 | set equal to 1989 | |
| 1977-1984 | 3 | differential shift compared to 1993+ as for WC (same slope as 1993+) | 0 | differential shift compared to 1993+ as for paradoxus, slope 1/3 of inshore | species combined |
| 1985-1992 | 0 | linear change between 1984 and 1993 selectivity | 0 | linear change between 1984 and 1993 selectivity | species combined |
| 1993-2009 | 3 | two logistic + slope parameters estimated | 0 | same as SC inshore but shifted to the right by 10 cm, slope 1/3 of inshore | species combined |
| | 0 | female downscaling factor (av. of SC spring and autumn surveys's factors) | | | |
| 3. South coast inshore | - | - | 3 | two logistic + slope parameters estimated | *M. capensis* |
| 4. West coast longline | 3 | two logistic + slope parameters estimated | 0 | same as South Coast longline | species combined |
| 5. South coast longline | - | - | 3 | two logistic + slope parameters estimated | *M. capensis* |
| 6. South coast handline | - | - | 0 | average of South Coast longline and inshore | |
| West coast summer survey | | | | | |
| *Africana* old | 7 | estimated for 7 specified lengths | 7 | estimated for 7 specified lengths | species disaggregated |
| *Africana* new | 5 | same slope as old | 5 | same slope as old | species disaggregated |
| West coast winter survey | | | | | |
| *Africana* old | 7 | estimated for 7 specified lengths | 7 | estimated for 7 specified lengths | species disaggregated |
| South coast spring survey | | | | | |
| *Africana* old | 7 | estimated for 7 specified lengths | 7 | estimated for 7 specified lengths | species disaggregated |
| *Africana* new | 5 | same slope as old | 5 | same slope as old | species disaggregated |
| | 1 | female downscaling factor | | | |
| South coast autumn survey | | | | | |
| *Africana* old | 7 | estimated for 7 specified lengths | 7 | estimated for 7 specified lengths | species disaggregated |
| *Africana* new | 5 | same slope as old | 5 | same slope as old | species disaggregated |
| | 1 | female downscaling factor | | | |
| Total | 59 | | 49 | | |

Table App.8.II.5: Minus- and plus-groups taken for the surveys and commercial proportion at length data.

| SURVEY DATA | *M. paradoxus* | | *M. capensis* | |
|---|---|---|---|---|
| | Minus | Plus | Minus | Plus |
| West coast summer | 13 | 47 | 13 | 59 |
| West coast winter | 13 | 51 | 13 | 61 |
| South coast spring | 21 | 53 | 13 | 71 |
| South coast autumn | 21 | 65 | 13 | 69 |

| COMMERCIAL DATA | Minus | Plus |
|---|---|---|
| West coast offshore, species combined | 23 | 65 |
| South coast offshore, species combined | 27 | 75 |
| South coast inshore, *M. capensis* | 27 | 65 |
| West coast longline, species combined | 51 | 91 |
| South coast longline, *M. capensis* | 51 | 91 |
| Both coasts offshore, species combined | 25 | 65 |

# APPENDIX 8.III

# Age-reading error matrices for *Merluccius paradoxus and M. capensis*

## 8.III.1 Introduction

The current stock assessment models used for the South African *M. paradoxus* and *M. capensis* resources are age structured models, making use of ageing data, either in the form of catch-at-age data or more recently directly as age-length keys. Until this assessment the assumption had been made that age classes are determined without error, when in fact some level of misclassification is often to be expected. Age-reading error occurs when estimates of age based on reading hard structures such as otoliths differ from the true age of the animal concerned. There are two sources of uncertainty in the relationship between the ages obtained from reading otoliths and the true age of the animal: bias and imprecision. Ageing bias occurs when there is a systematic difference between the true age of an animal and the age assigned to it, whereas ageing imprecision occurs when age-reading errors occur at random (Punt *et al.* 2008).

Errors in ageing can be taken into account by supplying an ageing-error matrix (Fournier and Archibald 1982; Richards *et al.* 1992; Punt *et al.* 2008), which defines the probability of assigning a particular age to a fish with a given true age. The method described in Punt *et al.* (2008) is used here to construct such matrices for the two hake species for use in these assessments.

## 8.III.2 Data and Method

Punt *et al.* (2008) model the probability of reader $i$ (of $I$ readers) assigning an animal of true age $a$ an age of $a'$, $P^i(a'|a)$, by assuming that both the ageing bias and the age-reading error standard deviation depend on the reader and the true age of the animal, and that age-reading error is normally distributed about the expected age (i.e., the expected age given any bias in age reading):

$$P^i\left(a'|a,\varphi\right) \propto \exp\left[\frac{-\left(a'-b_a^i(\varphi)\right)^2}{2\left(\sigma_a^i(\varphi)\right)^2}\right] \qquad \text{(App.8.III.1)}$$

where

$b_a^i$ is the expected age when reader *i* determines the age of an animal of true age *a*;

$\sigma_a^i$ is the standard deviation for reader *i* of the age-reading error for animals of true age *a*; and

$\varphi$ is the vector of parameters that determines the age-reading error matrix.

The ageing bias is modelled by:

$$b_a = \begin{cases} b_L + \left(b_H - b_L\right)\dfrac{1-e^{-\lambda(a-L)}}{1-e^{-\lambda(H-L)}} & \text{if } \lambda \neq 0 \\ b_L + \left(b_H - b_L\right)\dfrac{a-L}{H-L} & \text{if } \lambda = 0 \end{cases} \qquad \text{(App.8.III.2)}$$

where

$b_L$ is the expected age of animal of pre-specified minimum age *L*;

$b_H$ is the expected age of animal of pre-specified maximum age *H*; and

$\lambda$ determines the extent of nonlinearity between the true age and the expected age (note that $\lambda$ =0 reflects the special case of linear dependence).

The age-reading error standard deviation is modelled by:

$$\sigma_a = \begin{cases} \sigma_L + \left(\sigma_H - \sigma_L\right)\dfrac{1-e^{-\alpha(a-L)}}{1-e^{-\alpha(H-L)}} & \text{if } \alpha \neq 0 \\ \sigma_L + \left(\sigma_H - \sigma_L\right)\dfrac{a-L}{H-L} & \text{if } \alpha = 0 \end{cases} \qquad \text{(App.8.III.3)}$$

where

$\sigma_L$ is the age-reading error standard deviation for a pre-specified minimum age *L*;

$\sigma_H$ is the age-reading error standard deviation for a pre-specified maximum age *H*; and

$\alpha$ determines the extent of nonlinearity between age and the age-reading error standard deviation (note that $\alpha = 0$ reflects the special case of linear dependence).

The values for the parameters that determine the age-reading error matrix for each reader are estimated by maximizing the following likelihood function:

$$L(A|\beta,\varphi) = \prod_{j=1}^{J} \sum_{a=L}^{H} \beta_a \prod_{i=1}^{I} P^i\left(a_{i,j}|a,\varphi\right) \qquad \text{(App.8.III.4)}$$

where

$a_{i,j}$ is the age assigned by reader *i* to the *j*th otolith;

*A* is the entire data set of otolith readings; and

$\beta_a$ are nuisance parameters that can be interpreted as the relative frequency of animals of (true) age *a* in the sample (rather than in the population from which the sample was taken).

In general, not all otoliths are read by all readers. Therefore, the likelihood function is more generally the product of eqn (App.8.III.4) over sets of otoliths that were all read by the same group of readers, and a separate set of $\beta$'s is estimated for each such set of otoliths.

For this hake case the ageing error matrices were computed for each species separately. The data were aggregated over sex and over all sources of data (survey, commercial offshore and commercial longline). For each species, the data were divided into three groups of three readers:

a) Alexia Daniels (AD), Luke Bester (LB) and 'Unknown Reader' (UR);

b) Kevin Gradie (KG), John Prinsloo (JP) and Andy Payne/Dave Japp (AP/DJ) (these two readers have been aggregated as they read otoliths only when KG and JP did not agree, so that relatively very few data are involved); and

c) Phoeby Mullins (PM), Teressa Akkers (TA) and Kashif Booley (KB).

Table App.8.III.1 give details on the data available for each group.

## 8.III.3 Results and Discussion

In each group of three readers, one reader at least was assumed to be unbiased, as the age-reading errors would be confounded otherwise (Punt *et al.*, 2008). For each group of three readers, Akaike's information criterion (AIC) was used to select among alternative models (including which reader should be assumed to be unbiased).

The final models for age-reading error are summarised in Table App.8.III.2, while Figures App.8.III.1 and App.8.III.2 show plots of the age-reading error matrices for each reader and species. Figure App.8.III.3 plots the estimated ageing bias for each reader within each set of three readers. The fact that in some instances there is a bias for the true age zero is related to the use of a minus group.

Table App.8.III.1: Number of aged hake by species for each reader.

| | | *M. capensis* | | | *M. paradoxus* | | |
|---|---|---|---|---|---|---|---|
| Source | Year | UR | AD | LB | UR | AD | LB |
| | | | | | 324 | | 324 |
| WC summer | 1999 | 314 | 351 | 358 | 263 | 299 | 299 |
| WC summer | 2006 | | | | | 465 | 465 |
| WC summer | 2007 | | 369 | 369 | | 554 | 554 |
| WC summer | 2008 | | 451 | 451 | | 409 | 409 |
| WC winter | 2004 | | 808 | 808 | | | |
| SC spring | 2006 | | | | | 243 | 243 |
| SC autumn | 1999 | | 265 | 264 | | 139 | 139 |
| SC autumn | 2005 | | | | | 192 | 192 |
| SC autumn | 2007 | | 626 | 626 | | 358 | 358 |
| SC autumn | 2008 | | 638 | 638 | | 214 | 214 |

| | | *M. capensis* | | | *M. paradoxus* | | |
|---|---|---|---|---|---|---|---|
| Source | Year | KG | JP | AP/DJ | KG | JP | AP/DJ |
| WC summer | 1992 | 389 | 389 | 33 | 310 | 310 | 44 |
| WC summer | 1993 | 351 | 351 | 62 | 311 | 311 | 49 |
| WC summer | 1994 | 282 | 282 | 6 | 290 | 290 | 4 |
| WC summer | 1995 | 0 | 368 | | 0 | 303 | 0 |
| SC autumn | 1992 | 329 | 329 | 91 | 40 | 40 | 5 |
| SC autumn | 1993 | 407 | 407 | 40 | 95 | 95 | 23 |
| SC autumn | 1994 | 390 | 391 | 83 | 72 | 69 | 27 |
| Comm Offshore | 1992 | 260 | 260 | 28 | 521 | 521 | 46 |
| Comm Offshore | 1993 | 115 | 115 | 17 | 645 | 645 | 75 |
| Comm Offshore | 1994 | 126 | 126 | 5 | 330 | 330 | 38 |
| Comm Longline | 1994 | | | | 314 | 314 | 9 |

| | | *M. capensis* | | | *M. paradoxus* | | |
|---|---|---|---|---|---|---|---|
| Source | Year | PM | TA | KB | PM | TA | KB |
| WC autumn | 1999 | 408 | 406 | 400 | 140 | 140 | 140 |

Table App.8.III.2: Selected model for age-reading error for each reader and species.

| | *M. paradoxus* | | *M. capensis* | |
|---|---|---|---|---|
| | bias | precision | bias | precision |
| AD | Eqn App.8.III.2 | Eqn App.8.III.3 | Eqn App.8.III.2 | Eqn App.8.III.3 |
| LB | Eqn App.8.III.2 | Eqn App.8.III.3 | Eqn App.8.III.2 | Eqn App.8.III.3 |
| UR | Unbiased | Eqn App.8.III.3 | Unbiased | Eqn App.8.III.3 |
| KG | Eqn App.8.III.2 | Eqn App.8.III.3 | Eqn App.8.III.2 | Eqn App.8.III.3 |
| JP | Eqn App.8.III.2 | Eqn App.8.III.3 | Eqn App.8.III.2 | Eqn App.8.III.3 |
| AP/DJ | Unbiased | Eqn App.8.III.3 | Unbiased | Eqn App.8.III.3 |
| PM | Linear | Eqn App.8.III.3 | Eqn App.8.III.2 | Eqn App.8.III.3 |
| TA | Unbiased | Eqn App.8.III.3* | Unbiased | Eqn App.8.III.3 |
| KB | As PM | As PM | As PM | Eqn App.8.III.3* |

* Eqn App.8.III.3 pertains to the coefficient of variation rather than the standard deviation.

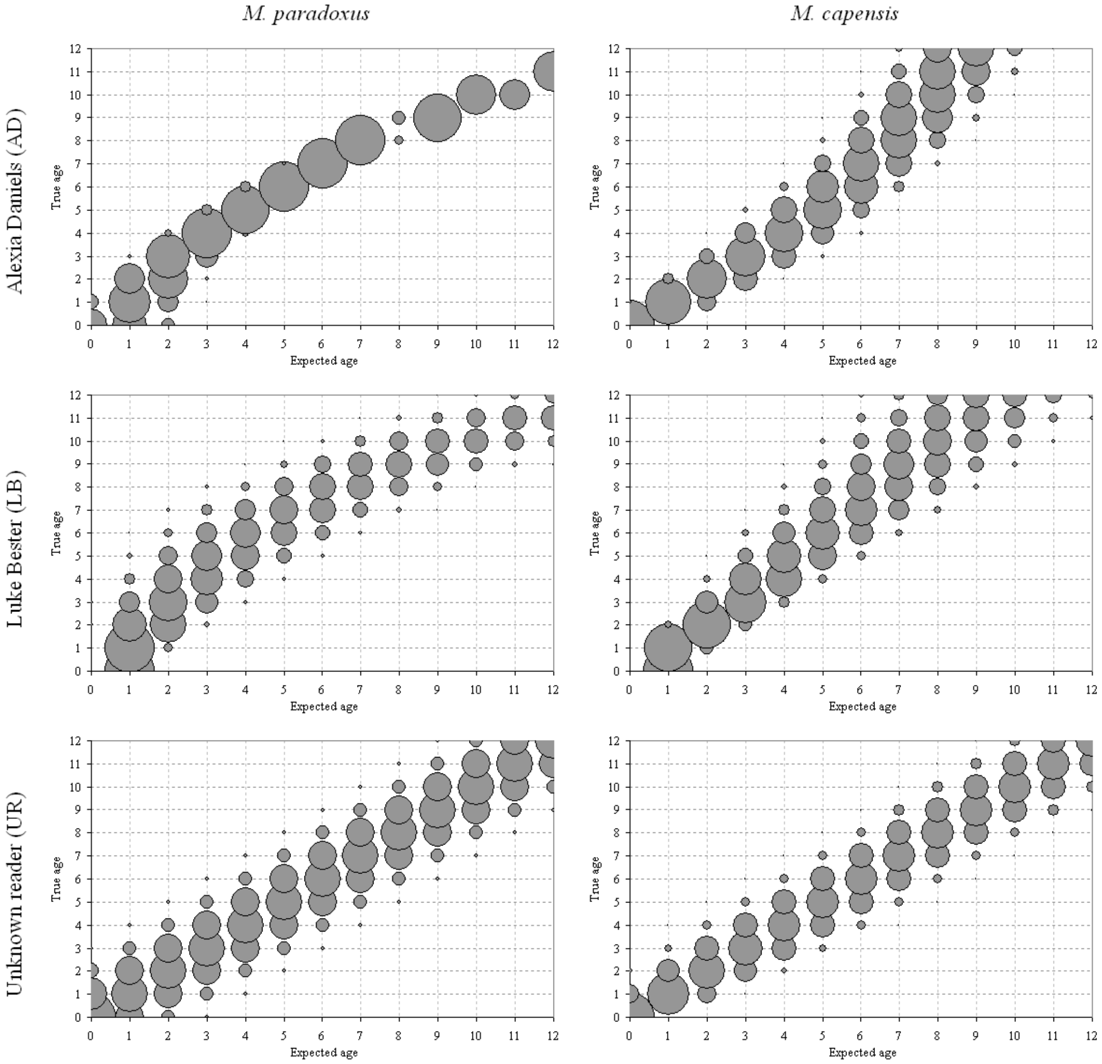


Figure App.8.III.1: Plots of the ageing-error matrices ('true' vs. expected age – the area of the bubble represents the proportion expected at each age) for *M. paradoxus* and *M. capensis*, for the two current readers (AD and LB) and the 'unknown reader'.

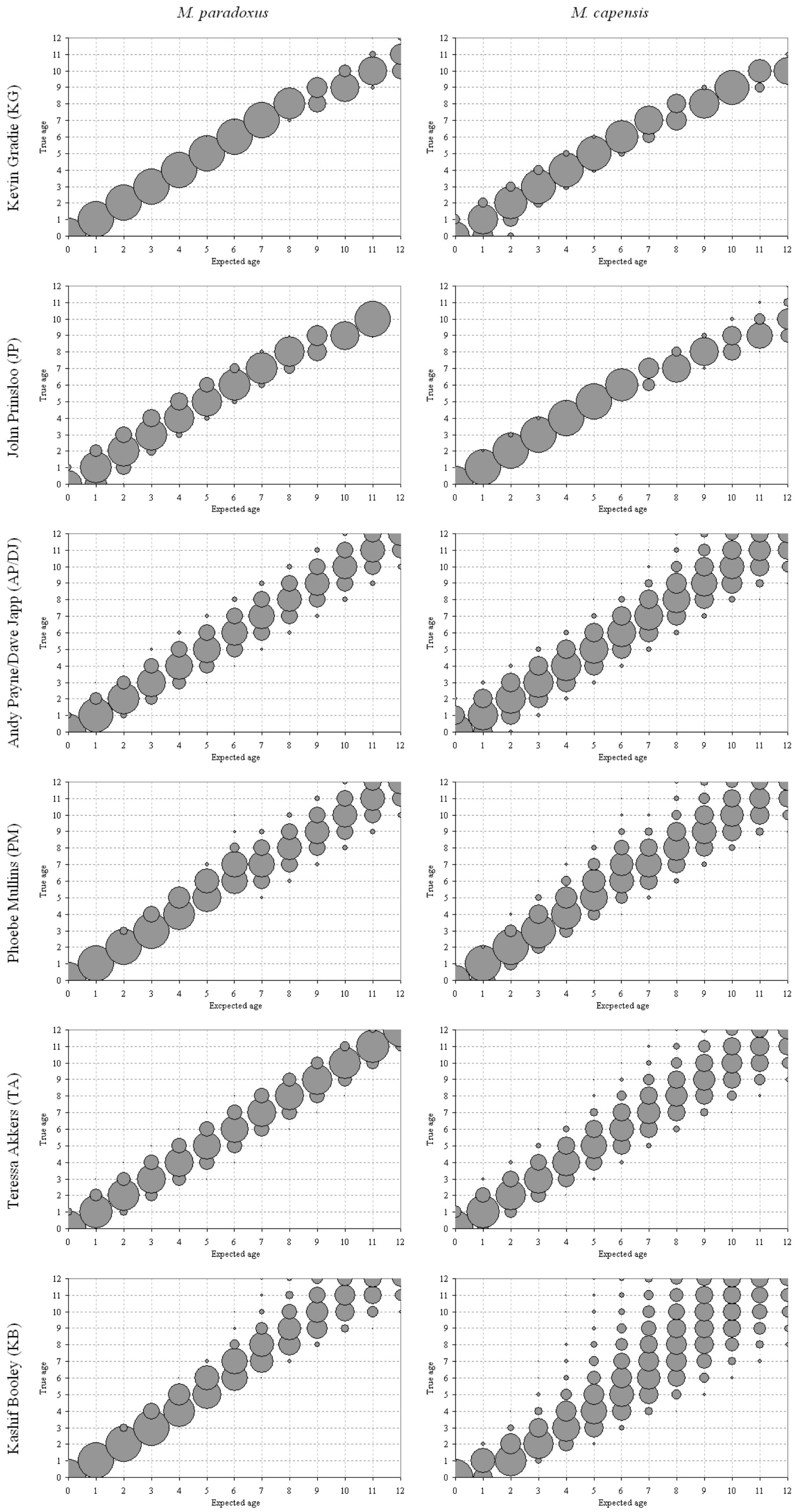


Figure App.8.III.2: Plots of the ageing-error matrices (‘true’ vs. expected age – the area of the bubble represents the proportion expected at each age) for *M. paradoxus* and *M. capensis* for past readers (KG, JP, AP/DJ, PM and KB).

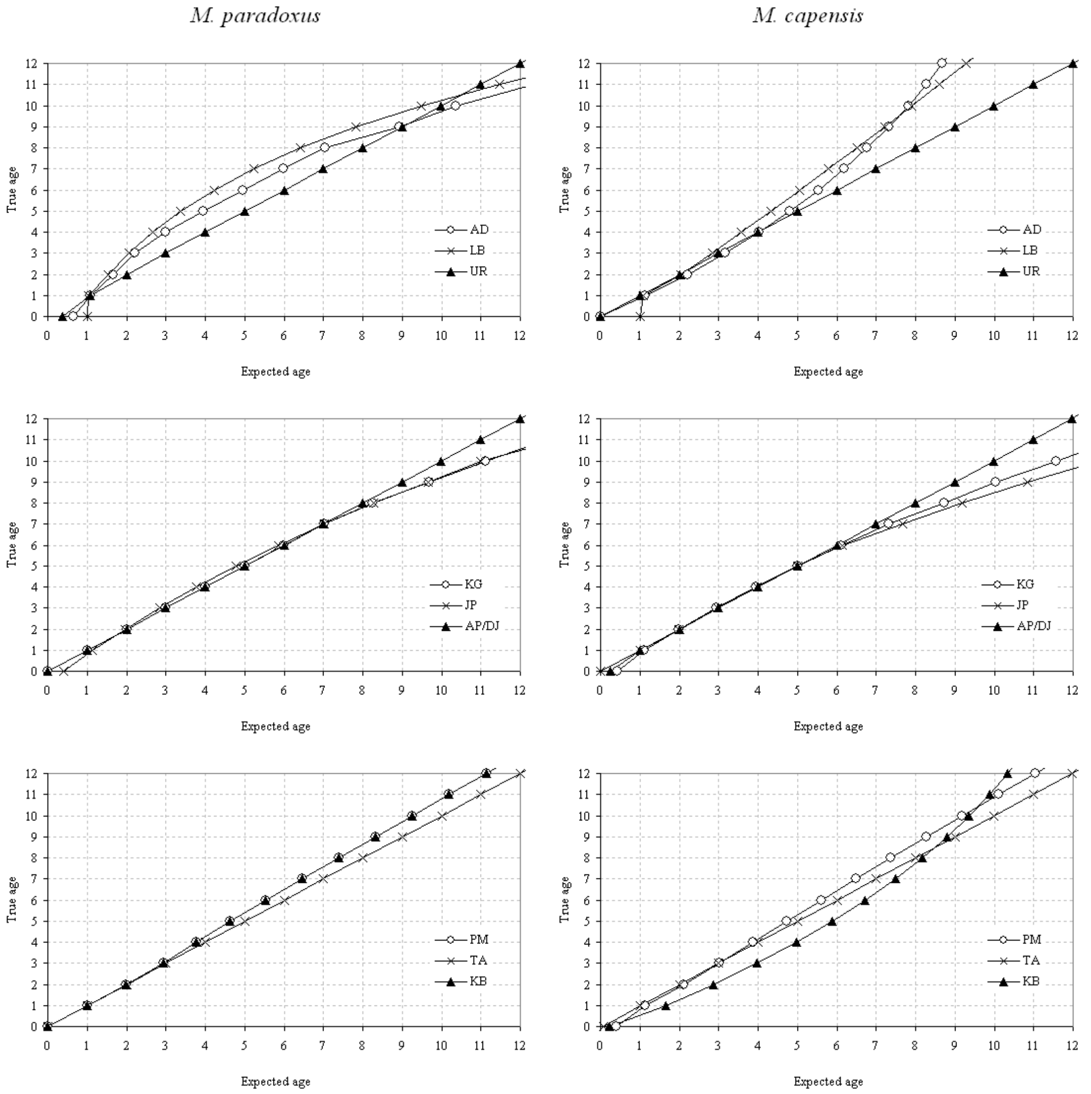


Figure App.8.III.3: Plots of the true vs. mean expected age across readers for *M. paradoxus* and *M. capensis*.

# Chapter 9 The development of a Reference Set and robustness tests for OMP-2011 testing

# Chapter 9

# The development of a Reference Set and robustness tests for OMP-2011 testing

## Summary

A Reference Set (RS) of 12 scenarios is selected as the primary basis to be used to simulation test candidates for the revised OMP for hake, OMP-2011. The principal uncertainty axes spanned by this RS are the central year for the switch from a primarily *M. capensis* to a primarily *M. paradoxus* fishery, values for natural mortality at age, and the form of the stock-recruitment relationship. The various data sets are generally reasonably fitted by these models, with the recent GLM-standardised CPUE series having the greatest influence. Results for conditioning of the full set of robustness/sensitivity tests are also given. Projections are carried out under a constant catch strategy to select a core set of robustness tests to run in the CMP selection process.

## 9.1 Introduction

The first aim of this Chapter is to describe the primary uncertainties of the New Reference Case and present the set of Operating Models (OMs) to form a Reference Set (RS) to be used for testing a revised OMP for the hake resource (OMP-2011). Similar to 2006, three factors contribute to most of the variability in the assessment results:

a) pre-1978 species split of the offshore trawl catches
b) natural mortality at age specifications; and
c) the stock-recruitment relationship.

## 9.2 Uncertainty in past catches

Commercial catches are not disaggregated by species and hence the species split of the catches that are needed for an assessment capable of distinguishing the two species, is carried out external to the model. From 1978 onwards, the catches made by the offshore trawl fleet are split by species by applying survey-based species proportion-by-depth relationships. Prior to 1978, there is no depth information recorded for the landings and the catch data for the period 1917–1977 are split by assuming that the proportion of *M. capensis* caught follows a logistic function over this period. The RS of OMs used for the testing of OMP-2007 (Chapter 4) included three choices for the central shift year from a primarily *M. capensis* to a primarily *M. paradoxus* fishery: 1940, 1950 and 1957. The reasons later years were excluded is that they led to poorer fits to the data, and also to what was considered to be an unrealistically high ratio of the then current biomass of *M. capensis* to *M. paradoxus*.

Runs were carried out based on the new RC for the central year ranging from 1940 to 1972. Figure 9.1 shows time trends of the proportion of *M. capensis* in the catch for these alternatives. These results were repeated for three different choices for the natural mortality vector assumed. All runs show results for a modified Ricker choice for the stock-recruitment relationship, as for the new RC. Results are shown in Tables 9.1 and 9.2 which respectively list estimates and differences in –lnL from that for the best fitting of all these models. Results are shown for more choices for the central year for the intermediate natural mortality vector case than for the high and low options.

It is evident from the results in Table 9.1 that the two reasons for favouring earlier years for the control shift year in the previous RS (better likelihoods and plausible ratio of the current biomass of *M. capensis* to *M. paradoxus*) are no longer as strong. Amongst the scenarios shown, only for the 1972 choice does the likelihood deteriorate sufficiently to argue strongly against plausibility (except for the higher natural mortality option, but for that there are other questionable features such as the very low $B_{MSY}^{sp}/K^{sp}$ estimate and the highish current *M. capensis* to *M. paradoxus* biomass ratio). This latter concern does however now seem to come into play only for choices for the central year of 1970 and sometimes 1965.

An interesting feature of the results for *M. paradoxus* is that except at the extremes of the range for choice of the central year, the current spawning biomass $B^{sp}_{2009}$, expressed either in absolute terms or as a proportion of $B^{sp}_{MSY}$, does not change greatly as the choice for the central year is modified (though it does depend on the natural mortality vector chosen). This is an important result, as a key condition for the revised OMP, as set out in the MSC re-certification report for the hake trawl fishery (MSC 2010c), is consideration of limit reference points, and the defaults for these are typically $0.5B^{sp}_{MSY}$ (more discussion in Chapter 10). The assessments generally put *M. paradoxus* somewhat above or at least close to this default.

This in turn suggests that debate on the most appropriate choices for the central year in the RS scenarios may not be that crucial in terms of the performance which the new OMP needs to demonstrate.

In terms of likelihoods, there is little to choose amongst the various scenarios in Table 9.1, except that the choice of 1972 can likely be excluded. But this then means that the data are not able to reliably distinguish choices between 1940 and 1970. It is important to check whether other information might allow some discrimination within this range as the OMP needs to demonstrate robust performance across the chosen range.

## 9.2.1 Implications of the depths of trawling operations

Leslie and Glazer (2010) present information on the (recent) *M. capensis* : *M. paradoxus* species ratio in catches by depth range (their tables 1 (for offshore commercial catches) and 2 (for surveys) (reproduced here as Tables 9.3 and 9.4 respectively)). Assuming that the species ratio by depth range in the 1940s was similar to that estimated in recent years, they then infer the possible species composition of the hake catch in the late 1940s from the average fishing depths reported by Scott (1949): an average fishing depth of about 250-300m on the West coast in 1948 would suggest a *M. paradoxus* proportion of 63-89% in the hake catches at that time and with an average fishing depth of less than 180m on the Southeast coast, hake catches probably consisted of close to 100% *M. capensis*. With about 80% of the total hake catch taken from West coast grounds, 50-71% of the hake catch in 1948 may have been *M. paradoxus*.

Tables 9.3 and 9.4 are further contrasted with Table 9.5, which reports the species ratio for the cumulative catch to 1977 (after which data-based estimation replaces assumption) for alternative choices for the central shift year. If from Table 9.5 one notes, for example, that a central shift year choice of 1970 corresponds to a *M. capensis* overall proportion of 0.81, and contrasts this to the commercial catch information in Table 9.3, the coarse inference is that West Coast catches would have had to be restricted to less than some 200m depth until 1977 if the choice of a central shift year of 1970 (with a current *M. paradoxus* spawning biomass depletion of 0.37) is to be considered plausible.

The above is not an "exact" result, however, because although the dependence of estimates of current species depletion on the choice of the central shift year are primarily influenced by the species ratio for this cumulative catch, there is also some subsidiary dependence on how this ratio changes over time.

To investigate this further, guided by Leslie and Glazer (2010) who report that depths of fishing in 1949 already indicate a substantial proportion of *M. paradoxus* in the West Coast catch, results are given in Table 9.6 for the current spawning biomass depletions that follow for the new Reference Case for modifications of the ogive-based approach for splitting the catches by species from 1917 to 1977. Instead of setting the *M. capensis* ratio at the commencement of the fishery to 100% as in the new Reference Case, these modifications rather set these initial values lower as indicated in that Table. This is done for three central shift year choices.

Since there was relatively little hake catch made prior to 1949, results in Leslie and Glazer (2010) for the *M. capensis* proportion of the hake catch in that year provide some guidance as to the relative plausibility of the various depletion estimates in Table 9.6. In particular Leslie and Glazer (2010) infer a West Coast *M. capensis* proportion in 1949 of between 11 and 37%. This suggests that only the scenarios considered in the two rightmost columns of Table 9.6 are realistic, which in turn implies that the current spawning biomass depletion for *M. paradoxus* is no more than 16%.

In terms then of a selection for the Reference Set, these results suggest that the higher values of the central shift year are less plausible.

Another study conducted by SADSTIA and OLRAC (2010) about the depth distribution of hake trawling in the mid 20th century is however sharply at variance with the information in Scott (1949) and the consequent inferences drawn about the species split at that time by Leslie and Glazer (2010). SADSTIA and OLRAC (2010) grouped the South African trawling fleet into classes of vessel for a series of years over the period 1950-1975. Each class of vessel was then assumed to fish at depth which are beta-distributed on the interval [0, $D_C$] where *Dc* is the limiting depth for class C, with a beta parameter of 2 (see Figure 9.2, reproduced from SADSTIA and OLRAC (2010)). The effort for each vessel was calculated and the overall distributions of effort over depth for each year on each coast was computed (see Figure 9.3. reproduced from SADSTIA and OLRAC (2010)). Applying the species proportion by depth relationship developed by Gaylard and Bergh (2004), they conclude that the *M. capensis* proportion of the catch in the early 1950s would have been around 75%, whereas Leslie and Glazer (2010) places it between 29 and 50%.

The results however may be highly dependent on the assumption of a beta distribution with (in particular) a lower bound of 0 and a beta parameter of 2 to model the distribution of fishing by depth for different vessel classes. The alpha parameters of these functions are conditioned on the modal depth assigned for each class. This leads to distributions with a large proportion of the fishing at depths well below the modal depth (see Figure 9.2). These distributions could just as reasonably by modeled by truncated normals whose modes are set to the modal depth assigned for each class and standard deviations set by truncating such that the 95%-ile falls at the maximum depth for the class. This would make a major change to Figure 9.2 and consequently the key results in Figure 9.3, possibly rendering those compatible with the information provided in the paper by Scott (1949).

### 9.2.2 Freeing 1978 conditions - linked to pre-1978 split of the catch debate.

The new Reference Case starts in 1917 assuming pre-exploitation equilibrium at carrying capacity. An assessment was run with a more recent start year, 1978, assuming that the stock is at a fraction ($\theta$) of its pre-exploitation biomass in 1978 and that an average fishing proportion ($\zeta$) applies to the years immediately preceding 1978 (with $\theta$ and $\zeta$ estimated in the model fitting procedure). Although important information is then ignored (the decline in the historical CPUE series over the period 1954-1977), this method allows one to be free of any assumption regarding the pre-1978 species-split of the catches. Furthermore, assuming pre-exploitation equilibrium in 1917 as in the new RC might be constraining the fit to the recent catch-at-length and catch-rate data. This assessment is included in the list of robustness test (Rob17, see Section 9.4 below on robustness tests). Spawning biomass trajectories relative to pre-exploitation biomass for both species for this robustness test are very similar to those estimated in the new RC (Figure 9.6), with current depletions estimated at 16% for *M. paradoxus* and 50% for *M. capensis* (compared to 15% and 54% respectively for the new RC). Results in absolute terms differ however, and the current *M. capensis* : *M. paradoxus* spawning biomass ratio is estimated at about 58% for Rob17, compared to 121% for the new RC. Comparing the current depletion estimated for *M. paradoxus* in Rob17 with the depletions in Table 9.1 for a series of choices for the central year of the *M. capensis* to *M. paradoxus* shift would suggest again that central year should be pre-1965.

In light of these studies, it was agreed that the RS should be robust to any choice of the central year between 1950 and 1965.

## 9.3 The Reference Set

Two further aspects were found to account for most of the uncertainty regarding the key considerations of resource status and productivity: the natural mortality of each species and the stock-recruitment functions. Attempts to fit natural mortality at age vectors freely led to widely varying results from scenario to scenario, so it was considered best to fix two vectors which arguably span the plausible range: a high $M$ scenario of $M_2$=0.9, $M_5$=0.5. and a low $M$ scenario of $M_2$=0.6, $M_5$=0.25. For the stock-recruitment relationship, three options were put forward: a Beverton-Holt with the steepness parameter $h$ estimated or fixed, and a modified Ricker with $\gamma$ estimated (see equations App.8.II.4a,b).

The RS consists of 12 cases, detailed in Table 9.7. These 12 cases vary their choices of factors along the three axes that contribute most variability to assessment results. The primary design intended a full cross of 2 centre-years x 2 natural mortality vectors x 3 stock recruitment relationships, but subject to the constraint that a fit with a –lnL difference of more than about 15 from that for the best of the fits would be excluded on the basis of poor compatibility with the data. (Of course, in strict likelihood terms such a large difference implies enormously different relative likelihoods across these scenarios, but that would be over-interpreting the likelihood function used here which has not attempted to take full account of non-independence amongst the data fitted.)

With the Beverton-Holt fits indicating estimates of steepness *h* at its upper bound of 0.98, it was considered important to include scenarios with lower values of *h* in the RS to admit greater possibilities of recruitment overfishing taking place, but the –lnL difference constraint excluded three of the associated four scenarios, leaving only RS10 amongst the RS.

The primary RS runs combined either both high *Ms* or both low *M*s for the two species, *M. paradoxus* and *M. capensis*. Scenarios which crossed high and low *M* values across the two species were also investigated, but mainly found to fail to meet the –lnL difference criterion. However, one exception to this was a scenario (RS11) with both a good fit to the data and a qualitatively different trajectory for *M. capensis* (reflecting a rather more heavily depleted *M. capensis* resource than do the other scenarios). It is considered important to retain this in the RS, together with a variant with slightly different specifications of natural mortality at age for *M. capensis* (RS12) which also showed this different trajectory behaviour for *M. capensis*. In subsequent presentation of candidate OMP results, the RS is be split into two: RSa (RS1 to RS10) and RSb (RS11 to RS12), so as not to mix results across qualitatively different *M. capensis* trajectories. In presenting results for the RS, these are integrated over the OMs given equal weight to each component. It was a WG decision to give equal weighting to each of the OM.

The RS is completed by the "central" Reference Case scenario, corresponding to a mid-year choice for the shift from a primarily *M. capensis* to *M. paradoxus* fishery, and an average of the two *M* vectors for natural mortality at age. The modified Ricker was preferred to the Beverton-Holt stock recruitment relationship for this scenario because it tends to yield slightly better fits to the data. Most robustness tests are single factor variants of this RC.

All 12 scenarios forming the RS are given equal weight in the simulation.

Table 9.8 summarises the key management quantity estimates across the RS, while Table 9.9 compares the different contributions to the total negative log-likelihood.

Figure 9.4 plots the estimated spawning biomass trajectories for the RS. Figure 9.5 shows their fits to the CPUE series. Only the CPUE series fits have been shown here, because as is evident from Table 9.9 it is fits to the CPUE, and particularly the more recent GLM-CPUE series, that are the main determinants of the overall likelihood of the scenario.

Scenarios with the lower value of 0.25 for $M_{5+}$ often lead to arguably unrealistically high pristine spawning biomass values. These can however be reduced, with little impact on other important management-related variables, by postulating an increase in natural mortality at higher ages (see Rob16 results).

Fits of the assessment model to the data are generally reasonable. From Tables 9.9 and 9.12 it is evident that fits to the CPUE data and to the commercial catches-at-length are the primary determinants of the overall likelihood. The more recent GLM-standardised CPUE plays the greatest role, particularly for *M. paradoxus* where many of the model variants have some difficulty in matching the earliest and the very recent values.

The primary consideration in proposing a RS is that its component OMs should span most of the range of plausible possibilities for the underlying dynamics. Table 9.8 suggests that this criterion is reasonably satisfied for *M. paradoxus* depletion and productivity (reflected by MSY). There is lesser variability amongst the RSa depletion estimates for *M. capensis*, but the scenarios in RSb would seem adequate to cover the possibility that the RSa depletion estimates for *M. capensis* might be misleading.

## 9.4 Robustness tests

### 9.4.1 Tests related to *M. paradoxus*

Table 9.10 summarises the full set of robustness/sensitivity tests considered. Some of these tests should be considered as “sensitivities” rather than formal robustness tests to provide OMs for candidate OMP testing, because they are included more to indicate impacts of specification variation on results than as arguably alternative plausible representations of reality. While Rob1 to Rob29 involve different assumptions about the resource dynamics or past data, it is only in their projections that Rob30 to Rob38 change from the Reference Case (RS1).

Table 9.11 summarises the key management quantities for Rob1 to Rob29, while Table 9.12 compares their different contributions to the total negative log-likelihood. Figure 9.6 plots the estimated spawning biomass trajectories for these tests.

### 9.4.2 Tests related to *M. capensis*

The robustness tests described in Table 9.5 are based mostly on RS1, i.e. they are representative of RSa, for which *M. capensis* is currently well above MSYL. Robustness tests are also needed in the case when the extent of *M. capensis* depletion is estimated to be relatively high (RSb) and six robustness tests have been selected to be run on RS11 (one of the RSb OMs). For changes in the past, three of the four robustness tests selected for *M. paradoxus* robustness testing (see below) have been chosen (Rob5, Rob13 and Rob25, but not Rob17 which is of a different nature and does not show *M. capensis* to be heavily depleted) and for changes in the future, Rob37 (decrease in *K*) has been selected.

Table 9.8 summarises the key management quantities for the four tests based on RS11, while Table 9.9 compares their different contributions to the total negative log-likelihood. Figure 9.7 plots the estimated spawning biomass trajectories for these tests.

## 9.5 Constant catch projections

Projections have been carried out under a constant catch strategy of 150 000t. Although the final one or two CMPs are checked on the complete suite of robustness tests, only a selected subset of robustness tests are used to test the CMPs routinely. The intention here is therefore to reduce the number of robustness tests that are run routinely on the CMPs by selecting the ones which appear under constant catch projections to present the greatest challenges from a resource conservation perspective. (Naturally constant catch projections do not provide discrimination amongst tests that involve changes to default assumptions for aspects of future data such as changes in precision, so that such tests remain retained in this selected set.) A projected constant catch of 150 000t was chosen as this will be more informative (in terms of the poor resource conservation performers) than a constant catch set at the current TAC.

Three performance statistics ($B^{sp}_{2027}/B^{sp}_{MSY}$ , $B^{sp}_{2030}/K^{sp}$ and $B^{sp}_{2030}/B^{sp}_{2010}$ for the female component of the population) are plotted in Figure 9.8 and 9.9 for the full set of RS and robustness tests under a constant catch of 150 000t.

On this basis the following robustness tests related to *M. paradoxus* were retained in the selected set:

*Changes in the past*: robustness tests Rob5 (true Ricker), Rob13 (decrease in *K*), Rob17 (start in 1978) and Rob25 (lower steepness *h*).

*Changes in the future*: robustness tests 31f (case of no surveys and an undetected catchability trend for CPUE), Rob35 (undetected catchability trend for CPUE) and Rob37 (decrease in *K*).

With the exception of tests Rob31 and Rob35 for which constant catch trials do not provide a test of the issue involved, the reason for these selections is inadequate increase of spawning biomass towards its MSY level.

The four robustness tests related to *M. capensis* were retained in the selected set.

## 9.6 Summary of key changes and their implications

The key changes, and their implications, in the new RS compared to that of 2006 (Chapter 4) on which the previous OMP was based, are summarised below.

### 9.6.1 Important methodological changes

a) The assessment is now gender-disaggregated as well as species-disaggregated.

b) In earlier assessments the fitting was to catch- and survey-proportion-at-age estimates where these were available and to length distribution data where these age data were not (and this led to some inconsistencies in results), with selectivity taken to be age-specific. Now a consistent (by construction) approach is used throughout of fitting to the length distribution data for all years plus the age length keys where available, with selectivity taken more realistically to be length-specific.

c) In the OMP-2007 RS, age-at-maturity was taken to be knife-edge at 4. Now recent fecundity-at-length information is input directly in ogive form; though the mean age at maturity is not too different, this does mean that some hake are mature at age 3, for example.

d) A generalised Ricker stock-recruitment curve is preferred to the Beverton-Holt, not only because it more readily allows the possibility of recruitment overfishing, but also particularly because it leads to better fits to the data. The effect of this tends to be to reduce the estimated $K$ but not the estimated $B_{\text{current}}$ (in terms of spawning biomass).

e) Data for four more years are now available, with data trends over that period indicating an improved *M. paradoxus* status.

## 9.6.2 Important changes to assessment results

a) Previously the $B_{\text{current}}/K$ for *M. paradoxus* spawning biomass for 2006 (median over RS of OMs) was about 8%. For the updated RS it is about 16%.

b) The *M. paradoxus* depletion is very sensitive to assumptions about the pre-1977 split of the catch between *M. capensis* and *M. paradoxus*. The previous assessment favoured (in likelihood terms) lower values in the range from 1940 to 1970 for the mid-year of the central year of the shift from a primarily *M. capensis* to a primarily *M. paradoxus* fishery, and this led to lower values for $B_{\text{current}}/K$ for *M. paradoxus*. However, the likelihoods for the current assessment no longer favour any choice of shift year within this 1940-1970 period. Historic information has been examined to throw light on this shift year, but different approaches yielded differing inferences. The *M. paradoxus* $B_{\text{current}}/K$ (in terms of spawning biomass) ranges from about 10% to a little over 30% across this range of values for the central shift year.

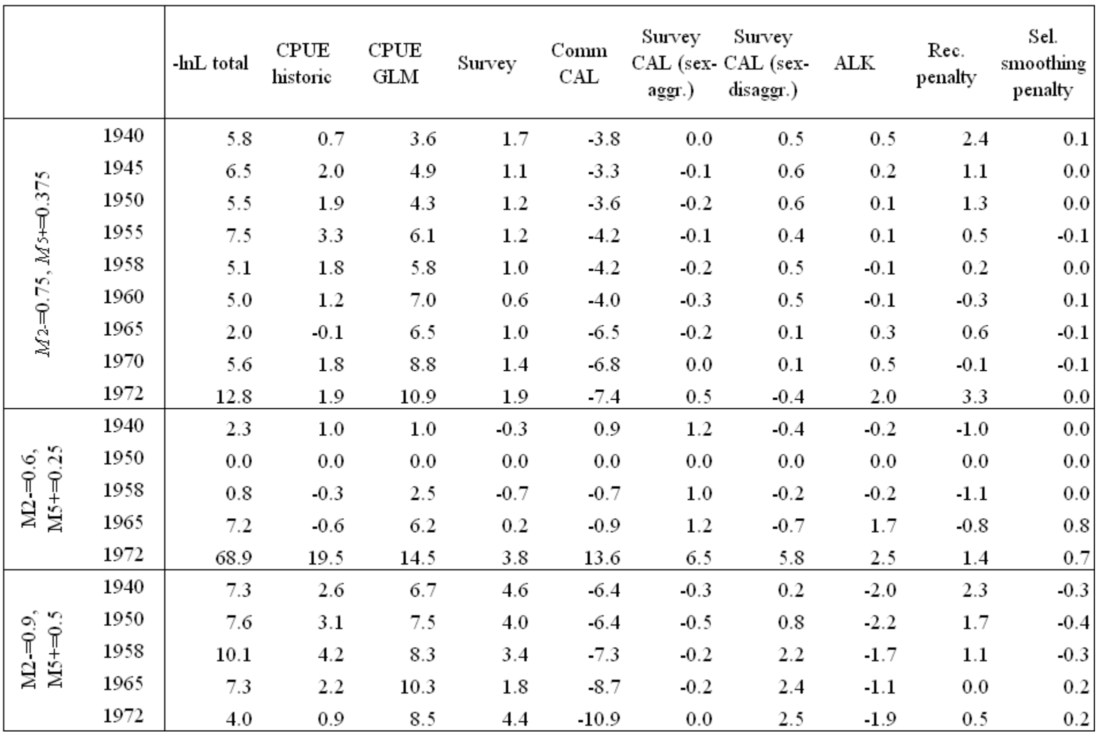
c) Importantly however, though $K$ estimates for *M. paradoxus* vary depending on the choice for this central shift year for the species dominating the catch, estimates of

$B_{\mathrm{current}}$ and $B_{MSY}$ are broadly stable across the range considered, with $B_{\mathrm{current}}/B_{MSY}$ quite consistently in the range of higher 50%s to lower 60%s. Thus the statistic $B_{\mathrm{current}}/B_{MSY}$ appears the more robustly estimated, which suggests using this as the primary measure on which to base reporting of current status and selection of recovery targets for *M. paradoxus* instead of $B_{\mathrm{current}}/K$.

Table 9.1: Estimates of management quantities for runs for a set of choices for the central year of the *M. capensis* to *M. paradoxus* shift, and for *M* values. Values in bold have been fixed. $B^{sp}_{2009}/K^{sp}$ is for both genders combined, while $B^{sp}_{MSY}/K^{sp}$ and $B^{sp}_{2009}/B^{sp}_{MSY}$ are in terms of the female only spawning biomass. A * on a value for steepness (*h*) indicates a constraint boundary; the species ratio values given relate to *M. capensis* relative to *M. paradoxus*.

| | | *M. paradoxus* | | | | | | | | | *M. capensis* | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | -lnL | $K^{sp}$ | $h$ | $B^{sp}_{2009}$ | $B^{sp}_{2009}/K^{sp}$ | $B^{sp}_{MSY}/K^{sp}$ | $B^{sp}_{2009}/B^{sp}_{MSY}$ | *MSY* | $M_{2-}$ | $M_{5+}$ | $K^{sp}$ | $h$ | $B^{sp}_{2009}$ | $B^{sp}_{2009}/K^{sp}$ | $B^{sp}_{MSY}/K^{sp}$ | $B^{sp}_{2009}/B^{sp}_{MSY}$ | *MSY* | $M_{2-}$ | $M_{5+}$ | 2009 species ratio $B^{sp}$ |
| 1940 | -93.9 | 2148 | 0.93 | 205 | 0.10 | 0.15 | 0.61 | 110 | **0.75** | **0.38** | 490 | 0.85 | 271 | 0.55 | 0.54 | 1.00 | 68 | **0.75** | **0.38** | 1.32 |
| 1945 | -93.1 | 1610 | 0.92 | 200 | 0.12 | 0.22 | 0.54 | 112 | **0.75** | **0.38** | 500 | 0.90 | 274 | 0.55 | 0.51 | 1.03 | 67 | **0.75** | **0.38** | 1.37 |
| 1950 | -94.1 | 1585 | 0.94 | 201 | 0.13 | 0.22 | 0.55 | 112 | **0.75** | **0.38** | 442 | 0.92 | 239 | 0.54 | 0.53 | 0.99 | 64 | **0.75** | **0.38** | 1.19 |
| 1955 | -92.1 | 1428 | 1.02 | 203 | 0.14 | 0.23 | 0.57 | 112 | **0.75** | **0.38** | 544 | 0.89 | 301 | 0.55 | 0.50 | 1.07 | 69 | **0.75** | **0.38** | 1.48 |
| 1958 | -94.5 | 1363 | 1.08 | 208 | 0.15 | 0.24 | 0.59 | 113 | **0.75** | **0.38** | 516 | 1.01 | 279 | 0.54 | 0.47 | 1.12 | 69 | **0.75** | **0.38** | 1.34 |
| 1960 | -94.6 | 1306 | 1.13 | 214 | 0.16 | 0.25 | 0.60 | 114 | **0.75** | **0.38** | 582 | 1.50* | 315 | 0.54 | 0.34 | 1.56 | 83 | **0.75** | **0.38** | 1.47 |
| 1965 | -97.7 | 1018 | 1.36 | 242 | 0.24 | 0.34 | 0.66 | 117 | **0.75** | **0.38** | 666 | 1.50* | 408 | 0.61 | 0.43 | 1.39 | 118 | **0.75** | **0.38** | 1.69 |
| 1970 | -94.0 | 644 | 1.38 | 240 | 0.37 | 0.50 | 0.69 | 120 | **0.75** | **0.38** | 1322 | 0.63 | 832 | 0.63 | 0.54 | 1.15 | 123 | **0.75** | **0.38** | 3.47 |
| 1972 | -86.9 | 543 | 1.20 | 230 | 0.42 | 0.58 | 0.71 | 113 | **0.75** | **0.38** | 1318 | 0.79 | 828 | 0.63 | 0.48 | 1.28 | 135 | **0.75** | **0.38** | 3.60 |
| 1940 | -97.3 | 2777 | 1.09 | 294 | 0.11 | 0.27 | 0.43 | 123 | **0.60** | **0.25** | 801 | 1.50* | 400 | 0.50 | 0.37 | 1.34 | 68 | **0.60** | **0.25** | 1.36 |
| 1950 | -99.6 | 2842 | 1.05 | 286 | 0.10 | 0.26 | 0.42 | 121 | **0.60** | **0.25** | 735 | 1.18 | 379 | 0.52 | 0.48 | 1.08 | 65 | **0.60** | **0.25** | 1.33 |
| 1958 | -98.9 | 2436 | 1.22 | 288 | 0.12 | 0.27 | 0.47 | 121 | **0.60** | **0.25** | 792 | 1.50* | 404 | 0.51 | 0.39 | 1.31 | 70 | **0.60** | **0.25** | 1.40 |
| 1965 | -92.4 | 1683 | 1.50* | 354 | 0.21 | 0.34 | 0.64 | 121 | **0.60** | **0.25** | 1793 | 1.50* | 1156 | 0.65 | 0.42 | 1.52 | 166 | **0.60** | **0.25** | 3.27 |
| 1972 | -30.7 | 1747 | 0.50 | 792 | 0.45 | 0.77 | 0.63 | 122 | **0.60** | **0.25** | 3113 | 0.45 | 2052 | 0.66 | 0.62 | 1.06 | 128 | **0.60** | **0.25** | 2.59 |
| 1940 | -92.3 | 1435 | 0.87 | 165 | 0.12 | 0.11 | 0.80 | 110 | **0.90** | **0.50** | 354 | 0.64 | 206 | 0.58 | 0.60 | 0.91 | 63 | **0.90** | **0.50** | 1.25 |
| 1950 | -92.0 | 967 | 0.86 | 156 | 0.16 | 0.19 | 0.65 | 110 | **0.90** | **0.50** | 367 | 0.62 | 214 | 0.58 | 0.61 | 0.91 | 63 | **0.90** | **0.50** | 1.37 |
| 1958 | -89.5 | 869 | 0.97 | 177 | 0.20 | 0.25 | 0.65 | 111 | **0.90** | **0.50** | 417 | 0.63 | 247 | 0.59 | 0.59 | 0.96 | 69 | **0.90** | **0.50** | 1.40 |
| 1965 | -92.3 | 662 | 1.14 | 199 | 0.30 | 0.37 | 0.68 | 111 | **0.90** | **0.50** | 442 | 1.50* | 279 | 0.63 | 0.41 | 1.44 | 110 | **0.90** | **0.50** | 1.40 |
| 1972 | -95.6 | 820 | 1.50* | 219 | 0.27 | 0.06 | 3.83 | 181 | **0.90** | **0.50** | 998 | 0.66 | 640 | 0.64 | 0.51 | 1.21 | 135 | **0.90** | **0.50** | 2.92 |

Table 9.2: For each contribution to the total negative log-likelihood (-lnL), differences in –lnL compared to the case with the lowest –lnL.



| | | -lnL total | CPUE historic | CPUE GLM | Survey | Comm CAL | Survey CAL (sex-aggr.) | Survey CAL (sex-disaggr.) | ALK | Rec. penalty | Sel. smoothing penalty |
|---|---|---|---|---|---|---|---|---|---|---|---|
| $M_2$=0.75, $M_{5+}$=0.375 | 1940 | 5.8 | 0.7 | 3.6 | 1.7 | -3.8 | 0.0 | 0.5 | 0.5 | 2.4 | 0.1 |
| | 1945 | 6.5 | 2.0 | 4.9 | 1.1 | -3.3 | -0.1 | 0.6 | 0.2 | 1.1 | 0.0 |
| | 1950 | 5.5 | 1.9 | 4.3 | 1.2 | -3.6 | -0.2 | 0.6 | 0.1 | 1.3 | 0.0 |
| | 1955 | 7.5 | 3.3 | 6.1 | 1.2 | -4.2 | -0.1 | 0.4 | 0.1 | 0.5 | -0.1 |
| | 1958 | 5.1 | 1.8 | 5.8 | 1.0 | -4.2 | -0.2 | 0.5 | -0.1 | 0.2 | 0.0 |
| | 1960 | 5.0 | 1.2 | 7.0 | 0.6 | -4.0 | -0.3 | 0.5 | -0.1 | -0.3 | 0.1 |
| | 1965 | 2.0 | -0.1 | 6.5 | 1.0 | -6.5 | -0.2 | 0.1 | 0.3 | 0.6 | -0.1 |
| | 1970 | 5.6 | 1.8 | 8.8 | 1.4 | -6.8 | 0.0 | 0.1 | 0.5 | -0.1 | -0.1 |
| | 1972 | 12.8 | 1.9 | 10.9 | 1.9 | -7.4 | 0.5 | -0.4 | 2.0 | 3.3 | 0.0 |
| M2-=0.6, M5+=0.25 | 1940 | 2.3 | 1.0 | 1.0 | -0.3 | 0.9 | 1.2 | -0.4 | -0.2 | -1.0 | 0.0 |
| | 1950 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 |
| | 1958 | 0.8 | -0.3 | 2.5 | -0.7 | -0.7 | 1.0 | -0.2 | -0.2 | -1.1 | 0.0 |
| | 1965 | 7.2 | -0.6 | 6.2 | 0.2 | -0.9 | 1.2 | -0.7 | 1.7 | -0.8 | 0.8 |
| | 1972 | 68.9 | 19.5 | 14.5 | 3.8 | 13.6 | 6.5 | 5.8 | 2.5 | 1.4 | 0.7 |
| M2-=0.9, M5+=0.5 | 1940 | 7.3 | 2.6 | 6.7 | 4.6 | -6.4 | -0.3 | 0.2 | -2.0 | 2.3 | -0.3 |
| | 1950 | 7.6 | 3.1 | 7.5 | 4.0 | -6.4 | -0.5 | 0.8 | -2.2 | 1.7 | -0.4 |
| | 1958 | 10.1 | 4.2 | 8.3 | 3.4 | -7.3 | -0.2 | 2.2 | -1.7 | 1.1 | -0.3 |
| | 1965 | 7.3 | 2.2 | 10.3 | 1.8 | -8.7 | -0.2 | 2.4 | -1.1 | 0.0 | 0.2 |
| | 1972 | 4.0 | 0.9 | 8.5 | 4.4 | -10.9 | 0.0 | 2.5 | -1.9 | 0.5 | 0.2 |

Table 9.3: Average proportions of *M. capensis* and *M. paradoxus* per depth range for the West and South Coasts, estimated by applying the species splitting algorithm to the offshore commercial catch data included in the GLM over the period 2004-2008. (from Leslie and Glazer 2010, with permission).

| Depth | West Coast | | South Coast | |
|---|---|---|---|---|
| | *M. capensis* | *M. paradoxus* | *M. capensis* | *M. paradoxus* |
| 101-200m | 0.81 | 0.19 | 0.84 | 0.16 |
| 201-250m | 0.59 | 0.41 | 0.47 | 0.53 |
| 251-300m | 0.37 | 0.63 | 0.34 | 0.66 |
| 301-400m | 0.09 | 0.91 | 0.11 | 0.89 |
| 401-500m | 0.01 | 0.99 | 0.01 | 0.99 |
| >500m | 0.00 | 1.00 | 0.00 | 1.00 |

Table 9.4: Average proportions of *M. capensis* and *M. paradoxus* observed per depth range for the West and South Coasts observed during all research surveys by *FRS Africana* over the period 2001 to 2009. (from Leslie and Glazer 2010, with permission).

| Depth (m) | West Coast | | South Coast | |
|---|---|---|---|---|
| | *M. capensis* | *M. paradoxus* | *M. capensis* | *M. paradoxus* |
| 000-050 | 1.00 | 0.00 | 1.00 | 0.00 |
| 051-100 | 1.00 | 0.00 | 1.00 | 0.00 |
| 101-150 | 0.86 | 0.14 | 1.00 | 0.00 |
| 151-200 | 0.54 | 0.46 | 0.79 | 0.21 |
| 201-250 | 0.17 | 0.83 | 0.32 | 0.68 |
| 251-300 | 0.11 | 0.89 | 0.16 | 0.84 |
| 301-350 | 0.08 | 0.92 | 0.11 | 0.89 |
| 351-400 | 0.04 | 0.96 | 0.07 | 0.93 |
| 401-450 | 0.01 | 0.99 | 0.02 | 0.98 |
| 451-500 | 0.00 | 1.00 | 0.01 | 0.99 |
| 501-600 | 0.00 | 1.00 | | |

Table 9.5: West and South coasts cumulative (1917-1977) *M. capensis* proportion in the offshore trawl catches for a series of choices for the central year of the *M. capensis* to *M. paradoxus* shift.

| | West Coast | South Coast |
|---|---|---|
| 1940 | 0.28 | 0.62 |
| 1945 | 0.31 | 0.62 |
| 1950 | 0.35 | 0.62 |
| 1955 | 0.43 | 0.62 |
| 1958 | 0.49 | 0.62 |
| 1960 | 0.54 | 0.62 |
| 1965 | 0.67 | 0.63 |
| 1970 | 0.81 | 0.70 |
| 1972 | 0.87 | 0.76 |

Table 9.6: Estimated *M. paradoxus* and *M. capensis* current spawning biomass depletions for a series of initial (1917) *M. capensis* proportions in the offshore trawl catches for different central shift years.

| Central shift year | | Initial *M. capensis* proportion<br>WC: 100%<br>SC: 100% | <br>WC: 80%<br>SC: 100% | <br>WC: 60%<br>SC: 100% | <br>WC: 40%<br>SC: 100% | <br>WC: 40%<br>SC: 80% |
|---|---|---|---|---|---|---|
| 1958 | $B^{sp}_{2009}/K^{sp}$: *M. paradoxus* | 0.15 | 0.16 | 0.16 | 0.14 | 0.14 |
| | $B^{sp}_{2009}/K^{sp}$: *M. capensis* | 0.54 | 0.54 | 0.56 | 0.57 | 0.57 |
| 1965 | $B^{sp}_{2009}/K^{sp}$: *M. paradoxus* | 0.24 | 0.24 | 0.25 | 0.16 | 0.15 |
| | $B^{sp}_{2009}/K^{sp}$: *M. capensis* | 0.61 | 0.59 | 0.51 | 0.55 | 0.55 |
| 1970 | $B^{sp}_{2009}/K^{sp}$: *M. paradoxus* | 0.37 | | 0.34 | 0.10 | 0.10 |
| | $B^{sp}_{2009}/K^{sp}$: *M. capensis* | 0.63 | | 0.58 | 0.56 | 0.55 |

Table 9.7: Description of the 12 cases forming the RS.

| | Shif center | SR relationship | Natural mortality<br>*M. paradoxus* | <br>*M. capensis* |
|---|---|---|---|---|
| RS1 (RC) | 1958 | Modified Ricker | $M_{2-}$=0.75; $M_{5+}$=0.375 | $M_{2-}$=0.75; $M_{5+}$=0.375 |
| RS2 | 1950 | BH, $h$ estimated | $M_{2-}$=0.6; $M_{5+}$=0.25 | $M_{2-}$=0.6; $M_{5+}$=0.25 |
| RS3 | 1950 | BH, $h$ estimated | $M_{2-}$=0.9; $M_{5+}$=0.5 | $M_{2-}$=0.9; $M_{5+}$=0.5 |
| RS4 | 1965 | BH, $h$ estimated | $M_{2-}$=0.6; $M_{5+}$=0.25 | $M_{2-}$=0.6; $M_{5+}$=0.25 |
| RS5 | 1965 | BH, $h$ estimated | $M_{2-}$=0.9; $M_{5+}$=0.5 | $M_{2-}$=0.9; $M_{5+}$=0.5 |
| RS6 | 1950 | Modified Ricker | $M_{2-}$=0.6; $M_{5+}$=0.25 | $M_{2-}$=0.6; $M_{5+}$=0.25 |
| RS7 | 1950 | Modified Ricker | $M_{2-}$=0.9; $M_{5+}$=0.5 | $M_{2-}$=0.9; $M_{5+}$=0.5 |
| RS8 | 1965 | Modified Ricker | $M_{2-}$=0.6; $M_{5+}$=0.25 | $M_{2-}$=0.6; $M_{5+}$=0.25 |
| RS9 | 1965 | Modified Ricker | $M_{2-}$=0.9; $M_{5+}$=0.5 | $M_{2-}$=0.9; $M_{5+}$=0.5 |
| RS10 | 1965 | BH, $h$ = 0.7 | $M_{2-}$=0.9; $M_{5+}$=0.5 | $M_{2-}$=0.9; $M_{5+}$=0.5 |
| RS11 | 1950 | BH, $h$ estimated | $M_{2-}$=0.6; $M_{5+}$=0.25 | $M_{2-}$=0.9; $M_{5+}$=0.5 |
| RS12 | 1950 | BH, $h$ estimated | $M_{2-}$=0.6; $M_{5+}$=0.25 | $M_{2-}$=0.5; $M_{5+}$=0.5 |

Table 9.8: Estimates of management quantities for the RS. Values in bold have been fixed. $B^{sp}_{2009}/K^{sp}$ is for both genders combined, while $B^{sp}_{\mathrm{MSY}}/K^{sp}$ and $B^{sp}_{2009}/B^{sp}_{\mathrm{MSY}}$ are in terms of the female only spawning biomass. The horizontal line separates the two RS.

| | | *M. paradoxus* | | | | | | | | *M. capensis* | | | | | | | | 2009 |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | -lnL | $K^{sp}$ | $h$ | $B^{sp}_{2009}/K^{sp}$ | $B^{sp}_{\mathrm{MSY}}/K^{sp}$ | $B^{sp}_{2009}/B^{sp}_{\mathrm{MSY}}$ | $MSY$ | $M_{2-}$ | $M_{5+}$ | $K^{sp}$ | $h$ | $B^{sp}_{2009}/K^{sp}$ | $B^{sp}_{\mathrm{MSY}}/K^{sp}$ | $B^{sp}_{2009}/B^{sp}_{\mathrm{MSY}}$ | $MSY$ | $M_{2-}$ | $M_{5+}$ | species ratio $B^{sp}$ |
| RS1 | -94.5 | 1363 | 1.08 | 0.15 | 0.24 | 0.59 | 113 | **0.75** | **0.38** | 516 | 1.01 | 0.54 | 0.47 | 1.12 | 69 | **0.75** | **0.38** | 1.34 |
| RS2 | -86.6 | 3009 | 0.98* | 0.10 | 0.24 | 0.45 | 119 | **0.60** | **0.25** | 1990 | 0.98* | 0.57 | 0.20 | 2.88 | 89 | **0.60** | **0.25** | 3.80 |
| RS3 | -87.6 | 906 | 0.91 | 0.17 | 0.20 | 0.63 | 110 | **0.90** | **0.50** | 941 | 0.98* | 0.59 | 0.17 | 3.41 | 119 | **0.90** | **0.50** | 3.65 |
| RS4 | -76.0 | 3474 | 0.98* | 0.19 | 0.20 | 1.09 | 118 | **0.60** | **0.25** | 2853 | 0.98* | 0.64 | 0.20 | 3.24 | 128 | **0.60** | **0.25** | 2.78 |
| RS5 | -85.3 | 962 | 0.98* | 0.27 | 0.11 | 2.19 | 124 | **0.90** | **0.50** | 1061 | 0.98* | 0.61 | 0.17 | 3.54 | 134 | **0.90** | **0.50** | 2.46 |
| RS6 | -99.6 | 2842 | 1.05 | 0.10 | 0.26 | 0.42 | 121 | **0.60** | **0.25** | 735 | 1.18 | 0.52 | 0.48 | 1.08 | 65 | **0.60** | **0.25** | 1.33 |
| RS7 | -92.0 | 967 | 0.86 | 0.16 | 0.19 | 0.65 | 110 | **0.90** | **0.50** | 367 | 0.62 | 0.58 | 0.61 | 0.91 | 63 | **0.90** | **0.50** | 1.37 |
| RS8 | -92.4 | 1683 | 1.50* | 0.21 | 0.34 | 0.64 | 121 | **0.60** | **0.25** | 1793 | 1.50* | 0.65 | 0.42 | 1.52 | 166 | **0.60** | **0.25** | 3.27 |
| RS9 | -92.3 | 662 | 1.14 | 0.30 | 0.37 | 0.68 | 111 | **0.90** | **0.50** | 442 | 1.50* | 0.63 | 0.41 | 1.44 | 110 | **0.90** | **0.50** | 1.40 |
| RS10 | -82.8 | 1412 | **0.70** | 0.33 | 0.28 | 1.12 | 123 | **0.90** | **0.50** | 1861 | **0.70** | 0.65 | 0.30 | 2.10 | 170 | **0.90** | **0.50** | 2.57 |
| RS11 | -93.4 | 3024 | 0.98* | 0.10 | 0.24 | 0.44 | 118 | **0.60** | **0.25** | 788 | 0.39 | 0.18 | 0.41 | 0.42 | 40 | **0.90** | **0.50** | 0.49 |
| RS12 | -96.0 | 3022 | 0.98* | 0.10 | 0.24 | 0.45 | 118 | **0.60** | **0.25** | 804 | 0.39 | 0.17 | 0.41 | 0.39 | 40 | **0.50** | **0.50** | 0.45 |

* Constraint boundary

Table 9.9: For each contribution to the total negative log-likelihood (-lnL), differences in –lnL compared to the case with the lowest total –lnL (RS6) across the RS.

| | -lnL total | CPUE historic | CPUE GLM | Survey | Comm CAL | Survey CAL (sex-aggr.) | Survey CAL (sex-disaggr.) | ALK | Rec. penalty | Sel. smoothing penalty |
|---|---|---|---|---|---|---|---|---|---|---|
| RS1 | 5.1 | 1.8 | 5.8 | 1.0 | -4.2 | -0.2 | 0.5 | -0.1 | 0.2 | 0.0 |
| RS2 | 13.1 | -0.4 | 10.6 | -1.1 | 1.8 | 0.5 | 0.7 | 0.5 | -0.1 | 0.5 |
| RS3 | 12.0 | 3.2 | 15.1 | 3.1 | -8.4 | 0.2 | 1.2 | -2.0 | -0.1 | -0.2 |
| RS4 | 23.7 | 0.6 | 20.8 | 2.7 | -3.5 | -0.4 | -0.2 | 0.9 | 0.9 | 1.6 |
| RS5 | 14.4 | 2.1 | 15.1 | 3.8 | -8.1 | -0.8 | 2.2 | -1.1 | 0.5 | 0.2 |
| RS6 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 |
| RS7 | 7.6 | 3.1 | 7.5 | 4.0 | -6.4 | -0.5 | 0.8 | -2.2 | 1.7 | -0.4 |
| RS8 | 7.2 | -0.6 | 6.2 | 0.2 | -0.9 | 1.2 | -0.7 | 1.7 | -0.8 | 0.8 |
| RS9 | 7.3 | 2.2 | 10.3 | 1.8 | -8.7 | -0.2 | 2.4 | -1.1 | 0.0 | 0.2 |
| RS10 | 16.8 | 4.9 | 17.2 | 5.1 | -10.6 | -0.7 | 0.1 | -0.5 | 0.2 | 0.9 |
| RS11 | 6.2 | -0.5 | 7.2 | -1.3 | 1.4 | -0.3 | 2.1 | -0.8 | -0.5 | -1.1 |
| RS12 | 3.6 | -0.4 | 7.3 | -1.7 | 0.0 | 0.4 | 0.0 | 0.5 | -0.6 | -1.9 |

Table 9.10: Description of the robustness/sensitivity tests.

| | Shift center | SR relationship | Natural mortality | | Other |
|---|---|---|---|---|---|
| | | | *M. paradoxus* | *M. capensis* | |
| **Changes in the past** | | | | | |
| Rob1 | 1965 | BH, *h* estimated | $M_{2-}$=0.6; $M_{5+}$=0.25 | $M_{2-}$=0.9; $M_{5+}$=0.5 | |
| Rob2 | 1950 | BH, *h* estimated | $M_{2-}$=0.9; $M_{5+}$=0.5 | $M_{2-}$=0.6; $M_{5+}$=0.25 | |
| Rob3 | 1965 | BH, *h* estimated | $M_{2-}$=0.9; $M_{5+}$=0.5 | $M_{2-}$=0.6; $M_{5+}$=0.25 | |
| Rob4 | 1950 | True Ricker | $M_{2-}$=0.6; $M_{5+}$=0.25 | $M_{2-}$=0.6; $M_{5+}$=0.25 | |
| Rob5 | 1950 | True Ricker | $M_{2-}$=0.9; $M_{5+}$=0.5 | $M_{2-}$=0.9; $M_{5+}$=0.5 | |
| Rob6 | | | as RC | | $\sigma_R$ = 0.25 |
| Rob7 | | | as RC | | $W_{ALK}$ = 0.001 |
| Rob8 | | | as RC | | $W_{ALK}$ = 0.1 |
| Rob9 | | | as RC | | $W_{CAL}$ = 0.01 |
| Rob10 | | | as RC | | $W_{CAL}$ = 1.0 |
| Rob11 | | | as RC | | *M* gender dependent (+0.05 for males, -0.05 for females) |
| Rob12 | | | as RC | | All commercial and survey selectivity slopes (in cm$^{-1}$): a)+0.04, b) +0.02, c) -0.04 and d) -0.02 |
| Rob13 | | | as RC | | Decrease in *K* (30% linear decrease between 1980 and 2000 for both spp) |
| Rob14 | | | as RC | | Added weighting (5x) to last 5 year's CPUE and survey data to fit recent abundance indices more closely |
| Rob15 | | | as RC | | No shrinkage of recent recruitments towards the stock-recruitment relationship prediction |
| Rob 16 | | | as RS2 | | Increasing *M* at large ages (linear from 0.25 at age 8 to 1 at age 15) |
| Rob17 | | | as RC | | Start in 1978, estimating $\theta$ and $\zeta$ |
| Rob 18 | | | as RC | | Change in efficiency in the offshore trawl fleet 1994/1995 |
| Rob 19 | | | as RC | | Different CPUE series: a. all offshore vessels incl.; b. alt. depth stratifications; c. omit days with nominal CPUE=0; (d. updated after database check) |
| Rob 20 | | | as RC | | Survey calibration factor: a. incr. cap. factor to 0.9; b. decr. cap. factor to 0.6; c. both cap. and para. factors estimated |
| Rob 21 | | | as RC | | Ageing of both species out by one year |
| Rob 22 | | | as RC | | Ageing of both species to be halved |
| Rob 23 | | | as RC | | Alternative assumption for the cap. offshore selectivity |
| Rob 24 | | | as RC | | Alternative assumption re SC female paradoxus selectivity scaling factor: a. as lower; b. as higher |
| Rob 25 | | | as RC | | Alternative maturity-at-length with fixed lower *h* values |
| Rob 26 | | | as RC | | Include discards in the past |
| Rob 27 | | | as RC | | 40/60 male/female ratio at birth instead of 50/50 |
| Rob 28 | | | as RC | | Alternative species split algorithm (post-1978 catches and CPUE series) |
| Rob 29 | | | as RC | | From 1997 to 2002 q for CPUE dropped by 20% as a result of shorter tows |
| **Changes in the future** | | | | | |
| Rob 30 | | | as RC | | Maximum proportion of cohort catchable in one year decrease from 90% to 70% |
| Rob 31 | | | as RC | | Missing/reduced surveys in the future: a. no surveys; b. only WC surveys; c. only SC surveys; d. both surveys missing every 3 years; e. increase all future surveys CVs by multiplicative factor of sqrt(2); f. no surveys plus undetected increase catchability related to CPUE |
| Rob 32 | | | as RC | | Decrease all future survey CVs by a multiplicative factor of 1/sqrt(2) |
| Rob 33 | | | as RC | | MPA possible effects on future CPUE: a. no CPUE; b. new CPUE series with prior on *q*; c. new CPUE series with lower *q*; d. new CPUE series with higher *q*; and e. new CPUE series with no prior on *q* |
| Rob 34 | | | as RC | | Trend in $F_{ratio}$ over time in the future: a) 2% p.a. and b) -2% p.a., for 10 years then constant |
| Rob 35 | | | as RC | | Undectected 2% p.a. increase in catchability related to CPUE in the future |
| Rob 36 | | | as Rob26 | | Change in discard pattern in the future: a) past, but no future discards; b) past and future discards; c) past discards are halved in the future. |
| Rob 37 | | | as RC | | Decrease in *K* in the future (30% linear decrease between 2011 and 2016 for both spp) |
| Rob 38 | | | as RC | | Allow for serial correlation in recruitment residuals (estimate from RC fit) |

Table 9.11: Estimates of management quantities for RS1 and Rob1 to Rob29. $K^{sp}$ and $B^{sp}_{2009}/K^{sp}$ are for both genders combined, while $B^{sp}_{MSY}/K^{sp}$ and $B^{sp}_{2009}/B^{sp}_{MSY}$ are in terms of the female only spawning biomass.

| | | *M. paradoxus* | | | | | | | | *M. capensis* | | | | | | | | 2009 |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | -lnL total | $K^{sp}$ | $h$ | $\frac{B^{sp}_{2009}}{K^{sp}}$ | $\frac{B^{sp}_{MSY}}{K^{sp}}$ | $\frac{B^{sp}_{2009}}{B^{sp}_{MSY}}$ | $MSY$ | $M_{2-}$ | $M_{5+}$ | $K^{sp}$ | $h$ | $\frac{B^{sp}_{2009}}{K^{sp}}$ | $\frac{B^{sp}_{MSY}}{K^{sp}}$ | $\frac{B^{sp}_{2009}}{B^{sp}_{MSY}}$ | $MSY$ | $M_{2-}$ | $M_{5+}$ | spp ratio $B^{sp}$ |
| RS1 | -94.5 | 1395 | 1.06 | 0.15 | 0.24 | 0.59 | 113 | 0.75 | 0.38 | 499 | 1.41 | 0.52 | 0.36 | 1.39 | 70 | 0.75 | 0.38 | 1.21 |
| Rob1 | -81.0 | 3511 | 0.98* | 0.19 | 0.20 | 1.09 | 119 | 0.60 | 0.25 | 1030 | 0.98* | 0.60 | 0.16 | 3.59 | 131 | 0.90 | 0.50 | 0.94 |
| Rob2 | -82.0 | 911 | 0.90 | 0.17 | 0.20 | 0.62 | 109 | 0.90 | 0.50 | 2083 | 0.98* | 0.58 | 0.20 | 2.95 | 94 | 0.60 | 0.25 | 7.85 |
| Rob3 | -79.8 | 1049 | 0.92 | 0.28 | 0.17 | 1.47 | 122 | 0.90 | 0.50 | 3002 | 0.98* | 0.64 | 0.20 | 3.28 | 134 | 0.60 | 0.25 | 6.52 |
| Rob4 | -82.3 | 2210 | 1.21 | 0.18 | 0.42 | 0.49 | 133 | 0.60 | 0.25 | 774 | 1.50* | 0.50 | 0.38 | 1.30 | 68 | 0.60 | 0.25 | 0.95 |
| Rob5 | -81.0 | 717 | 1.01 | 0.28 | 0.39 | 0.58 | 120 | 0.90 | 0.50 | 413 | 1.02 | 0.56 | 0.40 | 1.30 | 68 | 0.90 | 0.50 | 1.14 |
| Rob6 | -85.5 | 1522 | 0.95 | 0.15 | 0.21 | 0.65 | 108 | 0.75 | 0.38 | 486 | 1.45 | 0.59 | 0.36 | 1.57 | 70 | 0.75 | 0.38 | 1.27 |
| Rob7 | -212.2 | 1567 | 1.02 | 0.15 | 0.24 | 0.61 | 117 | 0.75 | 0.38 | 423 | 1.32 | 0.54 | 0.35 | 1.42 | 71 | 0.75 | 0.38 | 0.97 |
| Rob8 | 958.2 | 1662 | 0.95 | 0.07 | 0.21 | 0.21 | 119 | 0.75 | 0.38 | 487 | 1.50* | 0.49 | 0.34 | 1.38 | 69 | 0.75 | 0.38 | 2.09 |
| Rob9 | -96.1 | 1816 | 0.97 | 0.08 | 0.20 | 0.24 | 133 | 0.75 | 0.38 | 608 | 1.15 | 0.56 | 0.43 | 1.27 | 77 | 0.75 | 0.38 | 2.49 |
| Rob10 | -678.5 | 941 | 1.19 | 0.30 | 0.30 | 0.88 | 113 | 0.75 | 0.38 | 609 | 0.41 | 0.67 | 0.83 | 0.77 | 69 | 0.75 | 0.38 | 1.44 |
| Rob11 | -92.1 | 1528 | 1.09 | 0.14 | 0.23 | 0.55 | 113 | 0.75 | 0.38 | 531 | 1.50* | 0.51 | 0.33 | 1.43 | 70 | 0.75 | 0.38 | 1.24 |
| Rob12a | -76.6 | 1748 | 0.96 | 0.19 | 0.29 | 0.68 | 122 | 0.75 | 0.38 | 620 | 0.78 | 0.56 | 0.52 | 1.06 | 69 | 0.75 | 0.38 | 1.03 |
| Rob12b | -88.2 | 1594 | 1.01 | 0.17 | 0.26 | 0.67 | 118 | 0.75 | 0.38 | 562 | 0.91 | 0.55 | 0.48 | 1.10 | 68 | 0.75 | 0.38 | 1.12 |
| Rob12c | -75.4 | 952 | 1.15 | 0.22 | 0.27 | 0.66 | 107 | 0.75 | 0.38 | 416 | 1.50* | 0.55 | 0.40 | 1.32 | 70 | 0.75 | 0.38 | 1.10 |
| Rob12d | -91.4 | 1219 | 1.12 | 0.17 | 0.26 | 0.58 | 110 | 0.75 | 0.38 | 458 | 1.50* | 0.52 | 0.36 | 1.38 | 69 | 0.75 | 0.38 | 1.17 |
| Rob13 | -69.4 | 876 | 1.31 | 0.21 | 0.34 | 0.63 | 95 | 0.75 | 0.38 | 639 | 0.95 | 0.34 | 0.26 | 1.24 | 44 | 0.75 | 0.38 | 1.17 |
| Rob14 | -236.4 | 1208 | 1.23 | 0.19 | 0.24 | 0.72 | 114 | 0.75 | 0.38 | 484 | 1.16 | 0.49 | 0.45 | 1.05 | 70 | 0.75 | 0.38 | 1.05 |
| Rob15 | -96.5 | 1464 | 0.98 | 0.15 | 0.22 | 0.65 | 110 | 0.75 | 0.38 | 518 | 1.06 | 0.53 | 0.45 | 1.14 | 68 | 0.75 | 0.38 | 1.25 |
| Rob16 | -85.6 | 2302 | 0.93 | 0.11 | 0.27 | 0.41 | 123 | 0.60 | 0.25 | 1343 | 0.98* | 0.52 | 0.22 | 2.38 | 88 | 0.60 | 0.25 | 2.80 |
| Rob17 | -73.3 | 2080 | 0.85 | 0.16 | 0.27 | 0.60 | 124 | 0.75 | 0.38 | 384 | 1.50* | 0.50 | 0.41 | 1.19 | 63 | 0.75 | 0.38 | 0.58 |
| Rob18 | -119.7 | 1184 | 1.27 | 0.21 | 0.24 | 0.79 | 115 | 0.75 | 0.38 | 502 | 1.24 | 0.55 | 0.41 | 1.31 | 70 | 0.75 | 0.38 | 1.14 |
| Rob19a | -124.3 | 1236 | 1.16 | 0.16 | 0.23 | 0.64 | 111 | 0.75 | 0.38 | 545 | 1.03 | 0.52 | 0.43 | 1.14 | 67 | 0.75 | 0.38 | 1.38 |
| Rob19b | -105.0 | 1315 | 1.12 | 0.15 | 0.23 | 0.59 | 112 | 0.75 | 0.38 | 525 | 0.95 | 0.56 | 0.48 | 1.13 | 68 | 0.75 | 0.38 | 1.53 |
| Rob19c | -98.6 | 1391 | 1.05 | 0.14 | 0.22 | 0.59 | 111 | 0.75 | 0.38 | 496 | 1.40 | 0.46 | 0.35 | 1.25 | 69 | 0.75 | 0.38 | 1.16 |
| Rob20a | -94.6 | 1395 | 1.06 | 0.15 | 0.24 | 0.59 | 113 | 0.75 | 0.38 | 498 | 1.42 | 0.51 | 0.36 | 1.38 | 70 | 0.75 | 0.38 | 1.20 |
| Rob20b | -92.4 | 1393 | 1.06 | 0.15 | 0.24 | 0.59 | 113 | 0.75 | 0.38 | 504 | 1.38 | 0.53 | 0.36 | 1.42 | 70 | 0.75 | 0.38 | 1.26 |
| Rob20c | -95.6 | 1406 | 1.05 | 0.14 | 0.24 | 0.55 | 112 | 0.75 | 0.38 | 498 | 1.41 | 0.51 | 0.36 | 1.39 | 70 | 0.75 | 0.38 | 1.28 |
| Rob21 | -72.5 | 1229 | 1.00 | 0.16 | 0.22 | 0.67 | 116 | 0.75 | 0.38 | 470 | 0.85 | 0.57 | 0.52 | 1.05 | 69 | 0.75 | 0.38 | 1.34 |
| Rob22 | -83.3 | 995 | 1.16 | 0.13 | 0.25 | 0.47 | 114 | 0.75 | 0.38 | 404 | 0.51 | 0.60 | 0.75 | 0.78 | 74 | 0.75 | 0.38 | 1.92 |
| Rob23 | -84.4 | 1468 | 1.01 | 0.18 | 0.26 | 0.65 | 114 | 0.75 | 0.38 | 743 | 0.78 | 0.57 | 0.50 | 1.13 | 74 | 0.75 | 0.38 | 1.62 |
| Rob24a | -94.6 | 1397 | 1.06 | 0.16 | 0.26 | 0.60 | 113 | 0.75 | 0.38 | 507 | 1.35 | 0.52 | 0.37 | 1.35 | 70 | 0.75 | 0.38 | 1.20 |
| Rob24b | -94.1 | 1394 | 1.06 | 0.15 | 0.23 | 0.59 | 113 | 0.75 | 0.38 | 491 | 1.47 | 0.51 | 0.34 | 1.43 | 70 | 0.75 | 0.38 | 1.20 |
| Rob25 | -43.1 | 1575 | 0.70 | 0.12 | 0.29 | 0.46 | 102 | 0.75 | 0.38 | 762 | 0.70 | 0.50 | 0.40 | 1.25 | 65 | 0.75 | 0.38 | 2.01 |
| Rob26 | -97.4 | 1510 | 1.06 | 0.15 | 0.23 | 0.61 | 113 | 0.75 | 0.38 | 492 | 1.50* | 0.47 | 0.31 | 1.45 | 86 | 0.75 | 0.38 | 1.02 |
| Rob27 | -91.2 | 1300 | 1.02 | 0.15 | 0.25 | 0.62 | 112 | 0.75 | 0.38 | 499 | 1.22 | 0.51 | 0.37 | 1.44 | 69 | 0.75 | 0.38 | 1.28 |
| Rob28 | -91.0 | 1106 | 1.24 | 0.17 | 0.23 | 0.66 | 107 | 0.75 | 0.38 | 532 | 1.02 | 0.52 | 0.46 | 1.09 | 70 | 0.75 | 0.38 | 1.49 |
| Rob29 | -95.6 | 1406 | 1.08 | 0.14 | 0.25 | 0.54 | 114 | 0.75 | 0.38 | 522 | 1.38 | 0.49 | 0.33 | 1.42 | 69 | 0.75 | 0.38 | 1.27 |

Table 9.12: For each contribution to the total negative log-likelihood (-lnL), differences in -lnL compared to the Reference Case (RS1).

|  | -lnL total | CPUE historic | CPUE GLM | Survey | Comm. CAL | Survey CAL (sex-aggr.) | Survey CAL (sex-disaggr.) | ALK | Recruitment penalty | Selectivity smoothing penalty |
|---|---|---|---|---|---|---|---|---|---|---|
| RS1 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 |
| Rob1 | 13.4 | -1.4 | 9.1 | 1.5 | -0.3 | 0.2 | 1.4 | -0.4 | 1.4 | 1.8 |
| Rob2 | 12.5 | 1.7 | 14.1 | 3.0 | -5.1 | 1.8 | -1.9 | -0.2 | 0.1 | -0.7 |
| Rob3 | 14.7 | 2.2 | 14.9 | 4.0 | -6.4 | 0.7 | -1.2 | 0.7 | -0.1 | 0.1 |
| Rob4 | 12.2 | 13.9 | -3.5 | -0.3 | 2.6 | 0.9 | -1.6 | 0.8 | -0.5 | 0.2 |
| Rob5 | 13.4 | 14.1 | 4.1 | 2.0 | -2.6 | -0.6 | -0.7 | -1.8 | -0.5 | -0.2 |
| Rob6 | 9.0 | -1.8 | 4.0 | 0.2 | 1.1 | -0.5 | 2.1 | -1.0 | 5.1 | -0.2 |
| Rob7* | -117.7 | -1.0 | -1.5 | -2.7 | 2.8 | 0.2 | -7.3 | -107.5 | 0.6 | -1.4 |
| Rob8* | 1052.6 | -2.9 | 7.3 | 11.5 | 13.6 | 6.1 | 14.8 | 1002.2 | 1.0 | -1.0 |
| Rob9* | -1.6 | -2.3 | -18.2 | -12.3 | 57.7 | 31.6 | 40.4 | -5.1 | -2.0 | -14.1 |
| Rob10* | -584.1 | 3.2 | 20.9 | 3.6 | -538.9 | -9.8 | -18.3 | 37.8 | 9.5 | 37.5 |
| Rob11 | 2.4 | -0.3 | -0.7 | -0.4 | -0.4 | -0.5 | 3.0 | 2.6 | -0.1 | -0.6 |
| Rob12a | 17.8 | 9.5 | -3.5 | 0.5 | 10.6 | -1.4 | 0.9 | 0.4 | 0.5 | 0.0 |
| Rob12b | 6.3 | 5.1 | -3.4 | 0.4 | 3.7 | -0.8 | 0.3 | 0.3 | 0.7 | 0.0 |
| Rob12c | 19.1 | 1.1 | 6.5 | 2.6 | 4.3 | 2.3 | -1.1 | 3.2 | 0.2 | 0.0 |
| Rob12d | 3.1 | 0.0 | 3.6 | 0.9 | -1.4 | 0.7 | -0.6 | 0.0 | 0.0 | 0.0 |
| Rob13 | 25.1 | 15.2 | 0.4 | 3.8 | -2.2 | 0.4 | -0.5 | 2.4 | 5.5 | -0.1 |
| Rob14* | -142.0 | -0.5 | -78.1 | -64.6 | -1.7 | 0.2 | 0.5 | 0.4 | 1.6 | 0.1 |
| Rob15 | -2.0 | -0.9 | -0.9 | 0.4 | -0.8 | -0.3 | -0.7 | 0.2 | 0.9 | -0.2 |
| Rob16 | 8.8 | -1.6 | 7.4 | -1.7 | 2.6 | 2.4 | 0.0 | 1.0 | -1.0 | 0.0 |
| Rob17* | 21.1 | - | -4.8 | -0.4 | -7.4 | -0.5 | -1.7 | 0.2 | -0.4 | -0.7 |
| Rob18 | -25.3 | -0.8 | -18.3 | -7.3 | -1.6 | -0.5 | 0.8 | 2.7 | 0.4 | -0.8 |
| Rob19a | -29.9 | -0.9 | -27.3 | 0.3 | -1.3 | -0.2 | 0.2 | 0.0 | -0.4 | -0.4 |
| Rob19b | -10.6 | -0.6 | -10.7 | 1.6 | -1.5 | 1.2 | 0.4 | -0.4 | -0.4 | -0.3 |
| Rob19c | -4.1 | -0.5 | -8.2 | 2.7 | 1.7 | -0.3 | 0.0 | -0.6 | 1.2 | -0.1 |
| Rob20a | -0.1 | 0.0 | -0.2 | 0.0 | 0.1 | 0.0 | 0.0 | 0.0 | 0.1 | -0.1 |
| Rob20b | 2.1 | 0.0 | 0.7 | 1.1 | -0.1 | 0.0 | 0.1 | 0.0 | -0.3 | 0.6 |
| Rob20c | -1.2 | -0.4 | 0.0 | 0.0 | 0.1 | -0.2 | -0.1 | -0.2 | 0.1 | -0.4 |
| Rob21 | 21.9 | 0.2 | 1.2 | -0.7 | -4.6 | -1.9 | -0.1 | 25.3 | 3.3 | -0.8 |
| Rob22 | 11.2 | -1.8 | 4.6 | -1.8 | -8.8 | 6.6 | 4.1 | 7.6 | 4.5 | -4.1 |
| Rob23 | 10.1 | 2.7 | -2.1 | 0.3 | 5.4 | 0.1 | 1.0 | 1.0 | 0.6 | 0.9 |
| Rob24a | -0.2 | 0.0 | 0.5 | -0.1 | -0.3 | -0.1 | -0.1 | 0.1 | 0.0 | 0.0 |
| Rob24b | 0.3 | 0.1 | -0.3 | 0.1 | 0.3 | 0.1 | 0.1 | 0.0 | 0.0 | 0.0 |
| Rob25 | 51.3 | 22.3 | 11.7 | -0.2 | -0.2 | 0.9 | 1.8 | 3.8 | 11.0 | 0.1 |
| Rob26 | -3.0 | -0.4 | -1.1 | -0.3 | 0.7 | -0.6 | -0.6 | 0.2 | -0.4 | -0.3 |
| Rob27 | 3.3 | -0.6 | -0.2 | -0.6 | -0.1 | 0.3 | 1.7 | 3.2 | 0.0 | -0.4 |
| Rob28 | 3.4 | -0.9 | 9.9 | -2.1 | -2.9 | 0.0 | 0.6 | 0.7 | -0.8 | -1.2 |
| Rob29 | -1.2 | -0.4 | -1.1 | -3.1 | 1.0 | 0.4 | 1.7 | -0.2 | 0.4 | 0.1 |

* These likelihood contributions are not comparable to the others because of different weightings or data.

Table 9.13: Estimates of management quantities for RS11 and three robustness tests based on this OM. $K^{sp}$ and $B^{sp}_{2009}/K^{sp}$ are for both genders combined, while $B^{sp}_{MSY}/K^{sp}$ and $B^{sp}_{2009}/B^{sp}_{MSY}$ are in terms of the female only spawning biomass.

| | | *M. paradoxus* | | | | | | | | *M. capensis* | | | | | | | | 2009 |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | -lnL total | $K^{sp}$ | $h$ | $\frac{B^{sp}_{2009}}{K^{sp}}$ | $\frac{B^{sp}_{MSY}}{K^{sp}}$ | $\frac{B^{sp}_{2009}}{B^{sp}_{MSY}}$ | $MSY$ | $M_{2-}$ | $M_{5+}$ | $K^{sp}$ | $h$ | $\frac{B^{sp}_{2009}}{K^{sp}}$ | $\frac{B^{sp}_{MSY}}{K^{sp}}$ | $\frac{B^{sp}_{2009}}{B^{sp}_{MSY}}$ | $MSY$ | $M_{2-}$ | $M_{5+}$ | spp ratio $B^{sp}$ |
| RS11 | -93.4 | 3024 | 0.98* | 0.10 | 0.24 | 0.44 | 118 | 0.60 | 0.25 | 788 | 0.39 | 0.18 | 0.41 | 0.42 | 40 | 0.90 | 0.50 | 0.49 |
| Rob5(RS11) | -76.6 | 2041 | 1.32 | 0.17 | 0.41 | 0.45 | 134 | 0.60 | 0.25 | 717 | 0.39 | 0.20 | 0.47 | 0.41 | 42 | 0.90 | 0.50 | 0.42 |
| Rob13(RS11) | -63.2 | 3328 | 0.97 | 0.09 | 0.17 | 0.65 | 86 | 0.60 | 0.25 | 524 | 0.88 | 0.31 | 0.17 | 1.74 | 42 | 0.90 | 0.50 | 0.51 |
| Rob25(RS11) | -65.5 | 3233 | 0.70 | 0.15 | 0.33 | 0.57 | 111 | 0.60 | 0.25 | 627 | 0.39 | 0.15 | 0.40 | 0.36 | 37 | 0.90 | 0.50 | 0.19 |

Table 9.14: For each contribution to the total negative log-likelihood (-lnL), differences in -lnL compared to RS11.

| | -lnL total | CPUE historic | CPUE GLM | Survey | Comm. CAL | Survey CAL (sex-aggr.) | Survey CAL (sex-disaggr.) | ALK | Recruitment penalty | Selectivity smoothing penalty |
|---|---|---|---|---|---|---|---|---|---|---|
| RS11 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 |
| Rob5(RS11) | 16.7 | 16.8 | 4.2 | -0.6 | -1.9 | -0.6 | 0.0 | 0.0 | -0.8 | -0.3 |
| Rob13(RS11) | 30.1 | 1.7 | -11.0 | 2.2 | 5.1 | 3.6 | 2.6 | 4.6 | 19.7 | 1.6 |
| Rob25(RS11) | 27.9 | 13.4 | 8.7 | 2.4 | -5.1 | -0.2 | 1.3 | 2.9 | 2.7 | 1.8 |

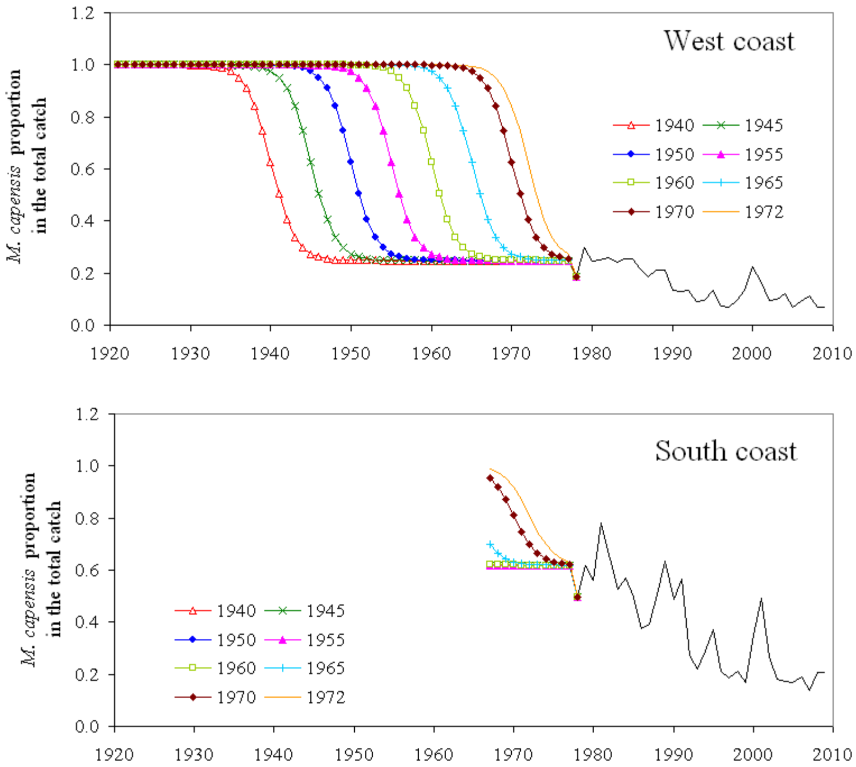


Figure 9.1: Assumed *M. capensis* proportion in the offshore trawl catches (West and South Coasts separately) for different choices for the central year for the switch from a primarily *M. capensis* to a primarily *M. paradoxus* deep-sea trawl fishery. From 1978 onwards, the survey species-proportion at depth relationship has been used to split the catches.

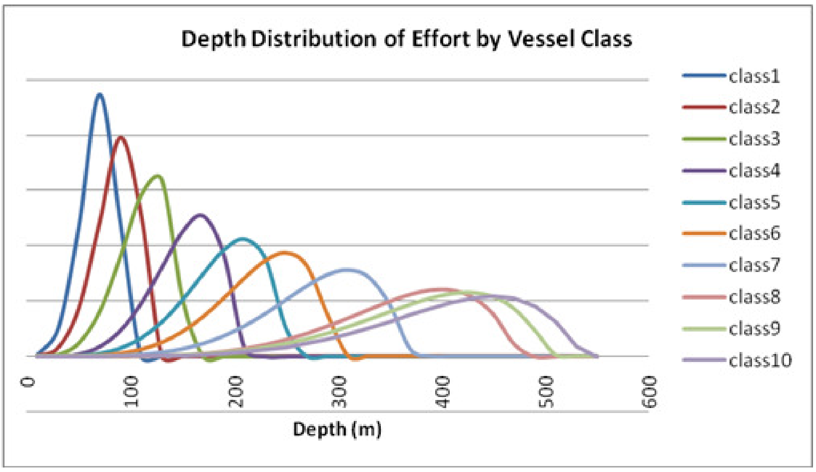


Figure 9.2: Beta distributions of effort over depth assumed for each of the 10 vessel classes (reproduced from SADSTIA and OLRAC (2010) with permission).

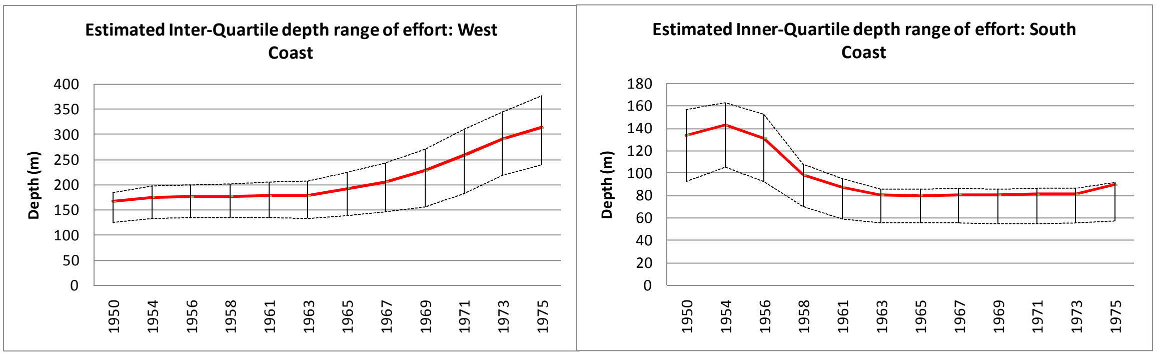


Figure 9.3: Estimated mean depth (solid red line) and the first and third quartiles (dashed lines) of the effort by depth distribution on the West and South coasts 1950 to 1975 (reproduced from SADSTIA and OLRAC (2010), with permission).

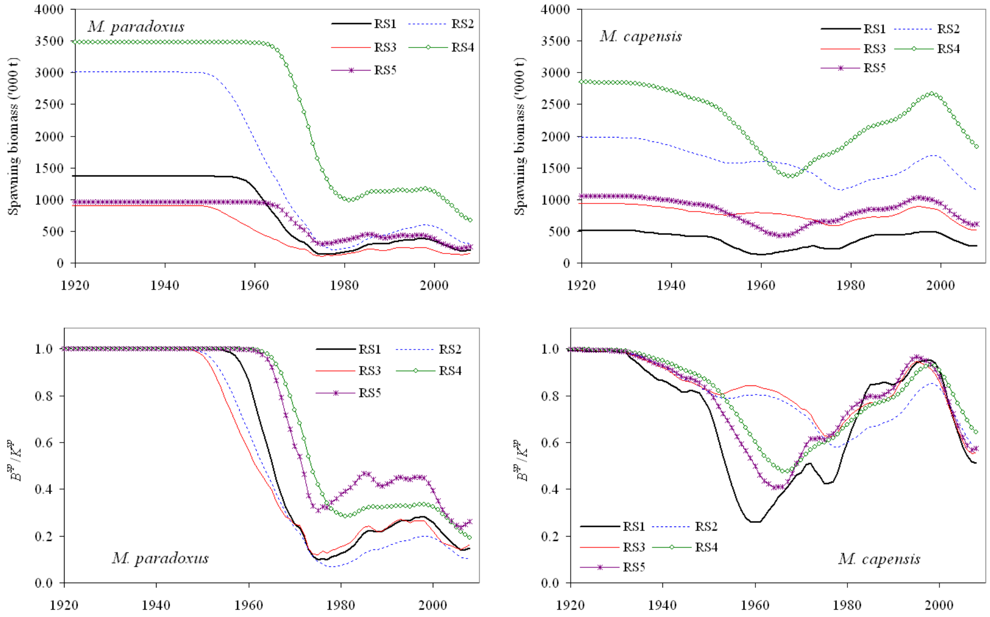


Figure 9.4a: Estimated spawning biomass trajectories for *M. paradoxus* and *M. capensis*, both in absolute terms and relative to the pre-exploitation level for RS1 to RS5.

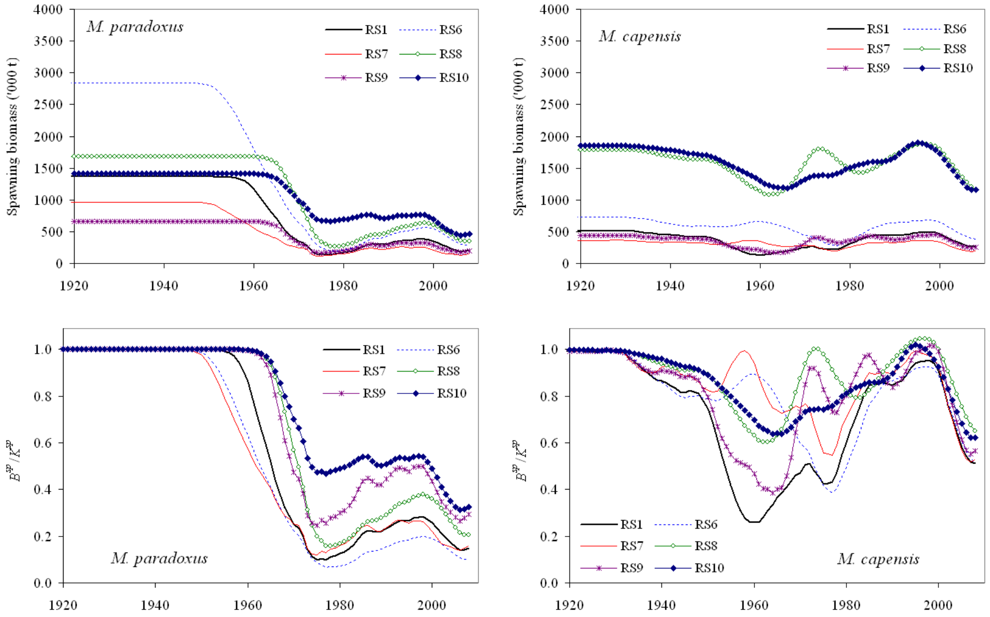


Figure 9.4b: Estimated spawning biomass trajectories for *M. paradoxus* and *M. capensis*, both in absolute terms and relative to the pre-exploitation level for RS1 and RS6 to RS10.

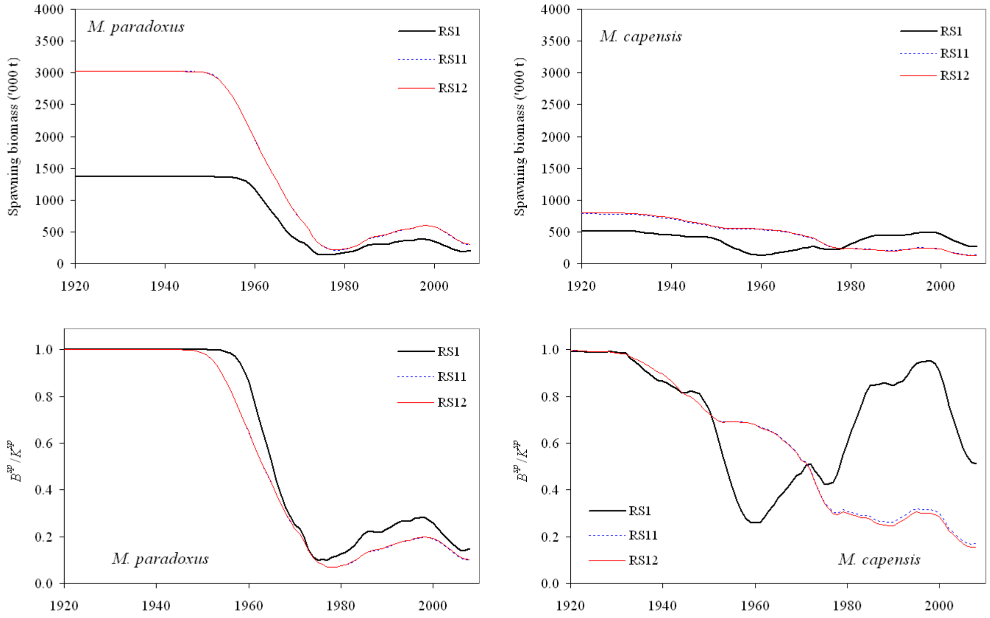


Figure 9.4c: Estimated spawning biomass trajectories for *M. paradoxus* and *M. capensis*, both in absolute terms and relative to the pre-exploitation level for RS1, RS11 and RS12. Note that the RS11 and RS12 trajectories are virtually on top of each other.

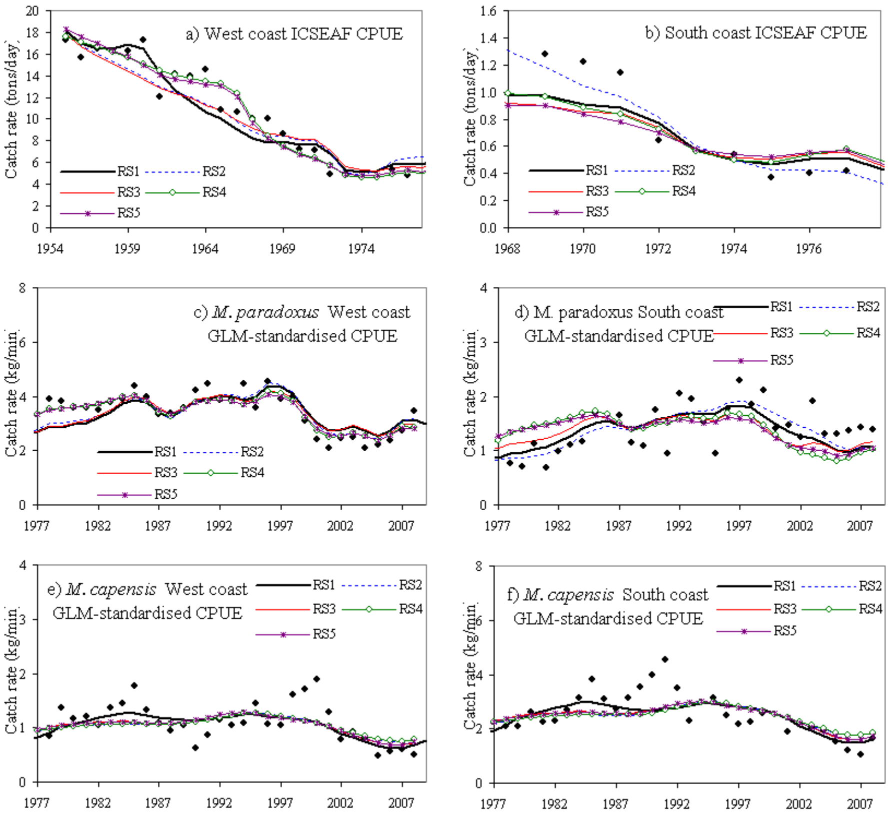


Figure 9.5a: Fit to the CPUE data for RS1 to RS5.

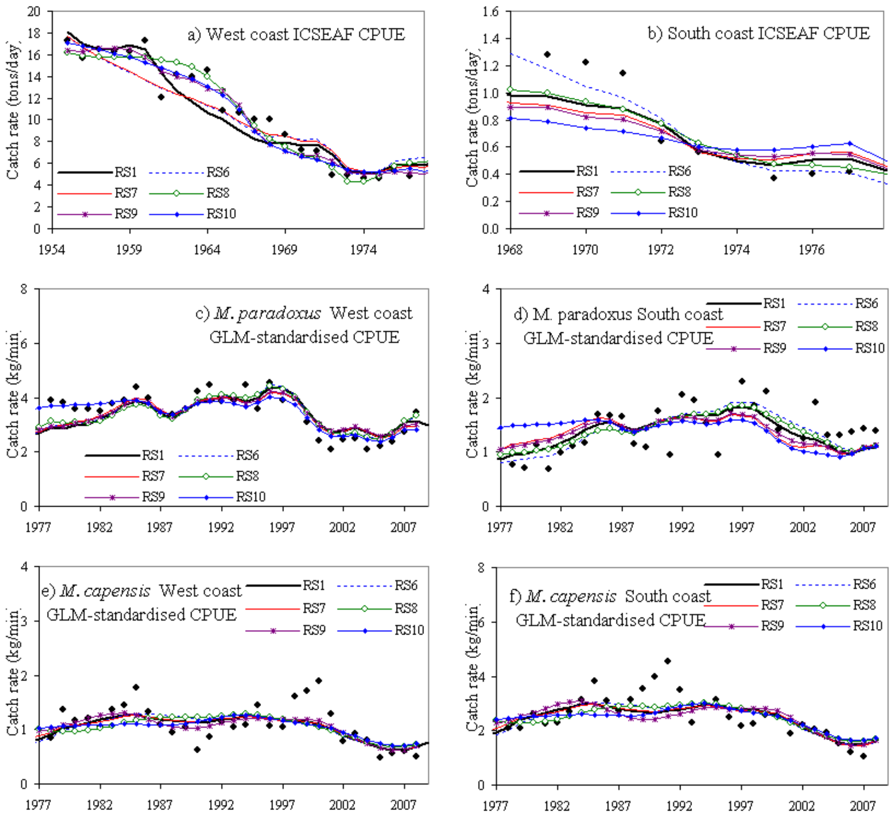


Figure 9.5b: Fit to the CPUE data for RS1 and RS6 to RS10.

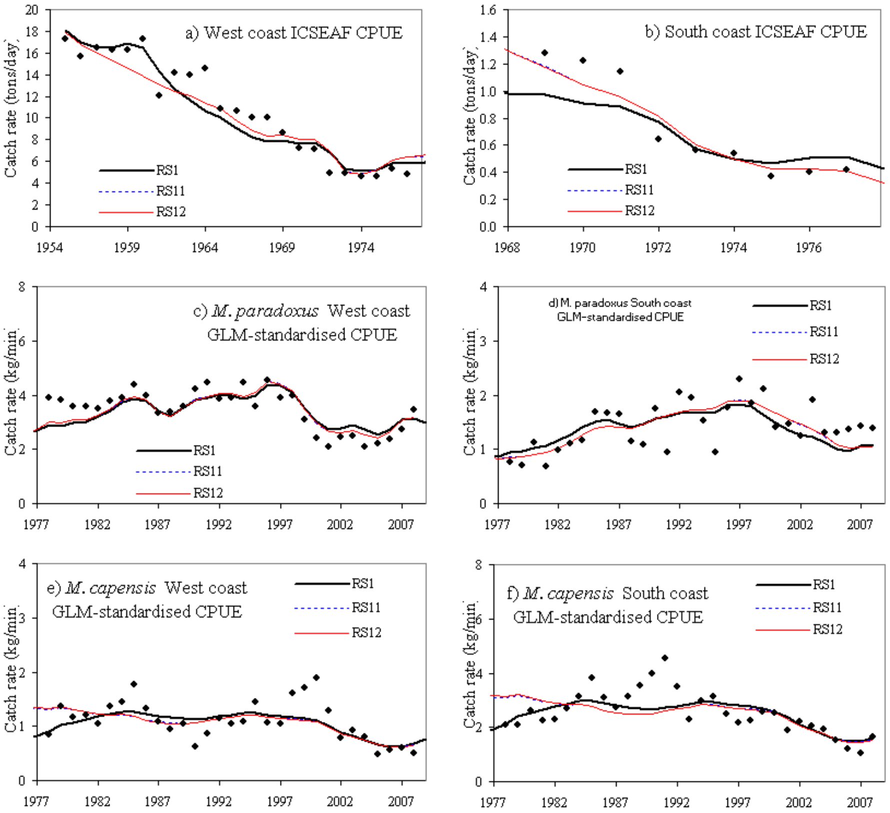


Figure 9.5c: Fit to the CPUE data for RS1, RS11 and RS12. Note that the RS11 and RS12 trajectories are virtually on top of each other.

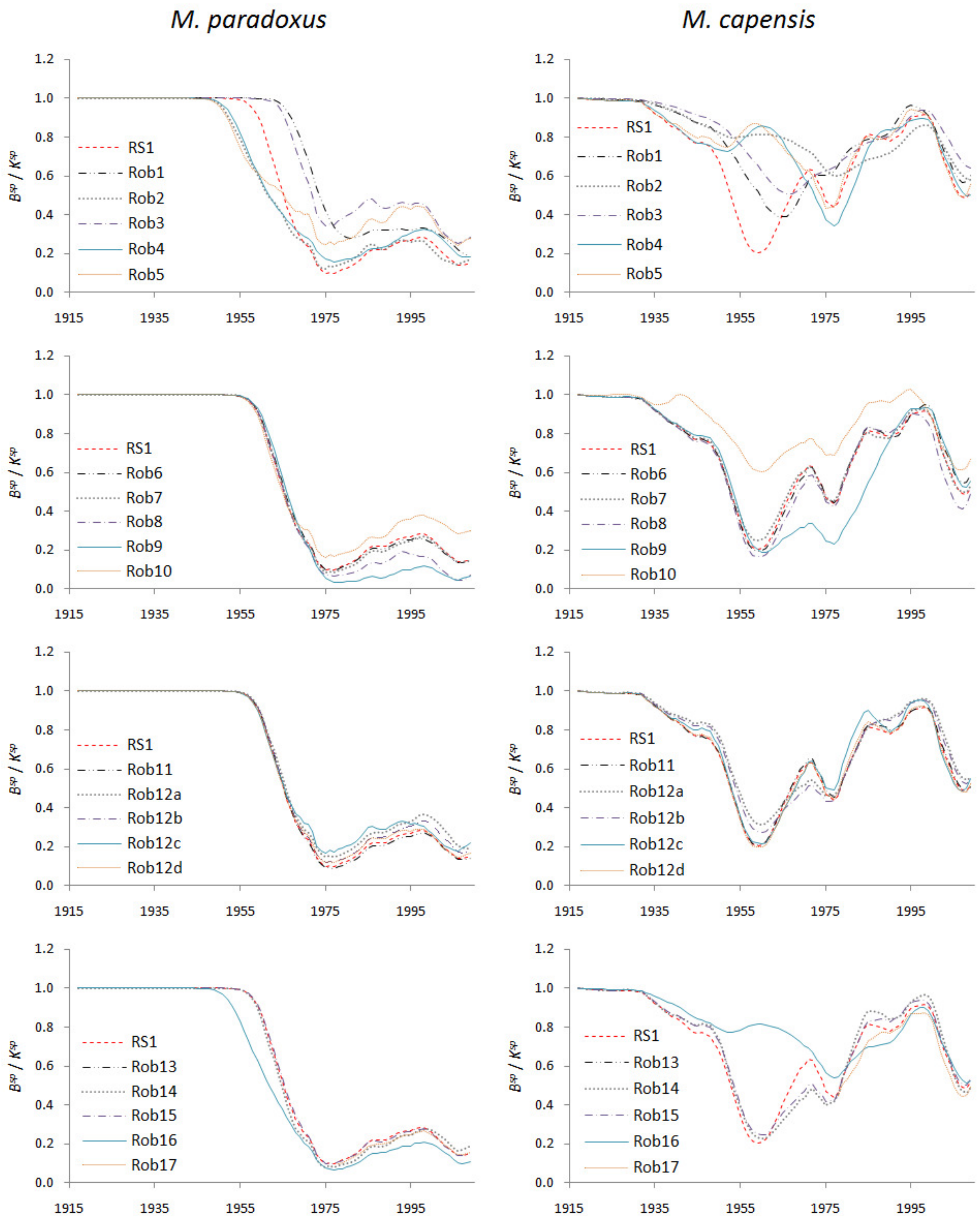


Figure 9.6: Estimated gender-aggregated spawning biomass trajectories for *M. paradoxus* and *M. capensis*, relative to pre-exploitation levels, for the RC (RS1) and robustness tests Rob1-Rob29.

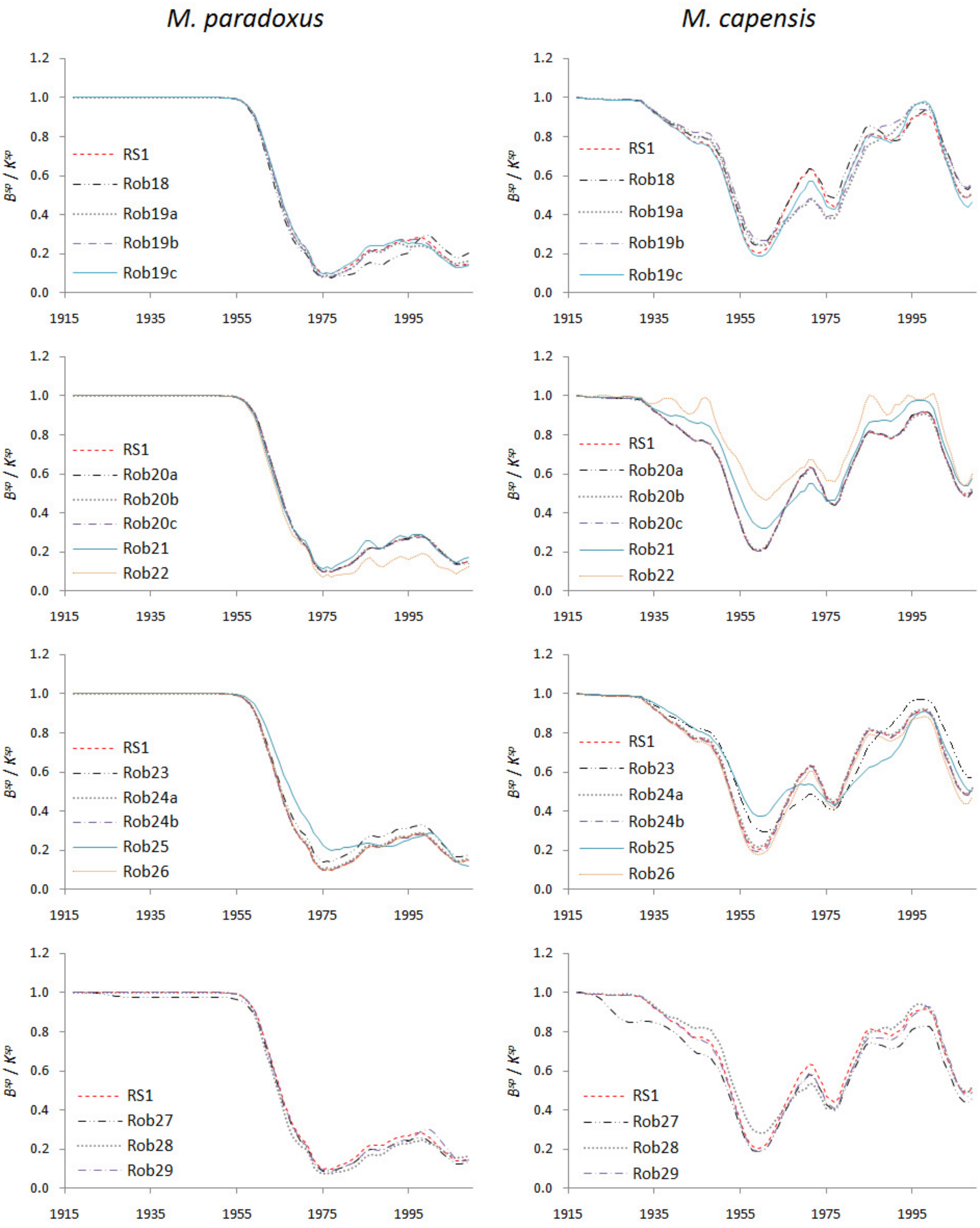


Figure 9.6: continued

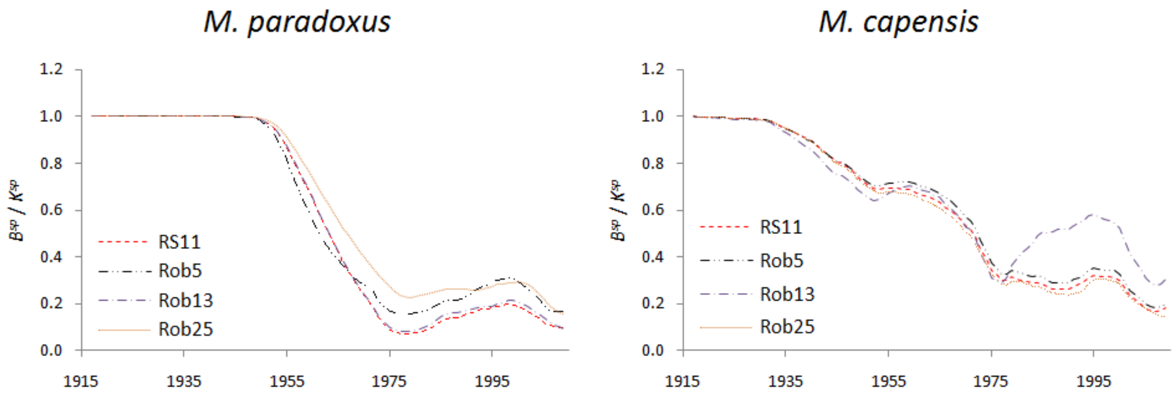


Figure 9.7: Estimated gender-aggregated spawning biomass trajectories for *M. paradoxus* and *M. capensis*, relative to pre-exploitation levels, for the RS11 and three robustness tests based on this OM.

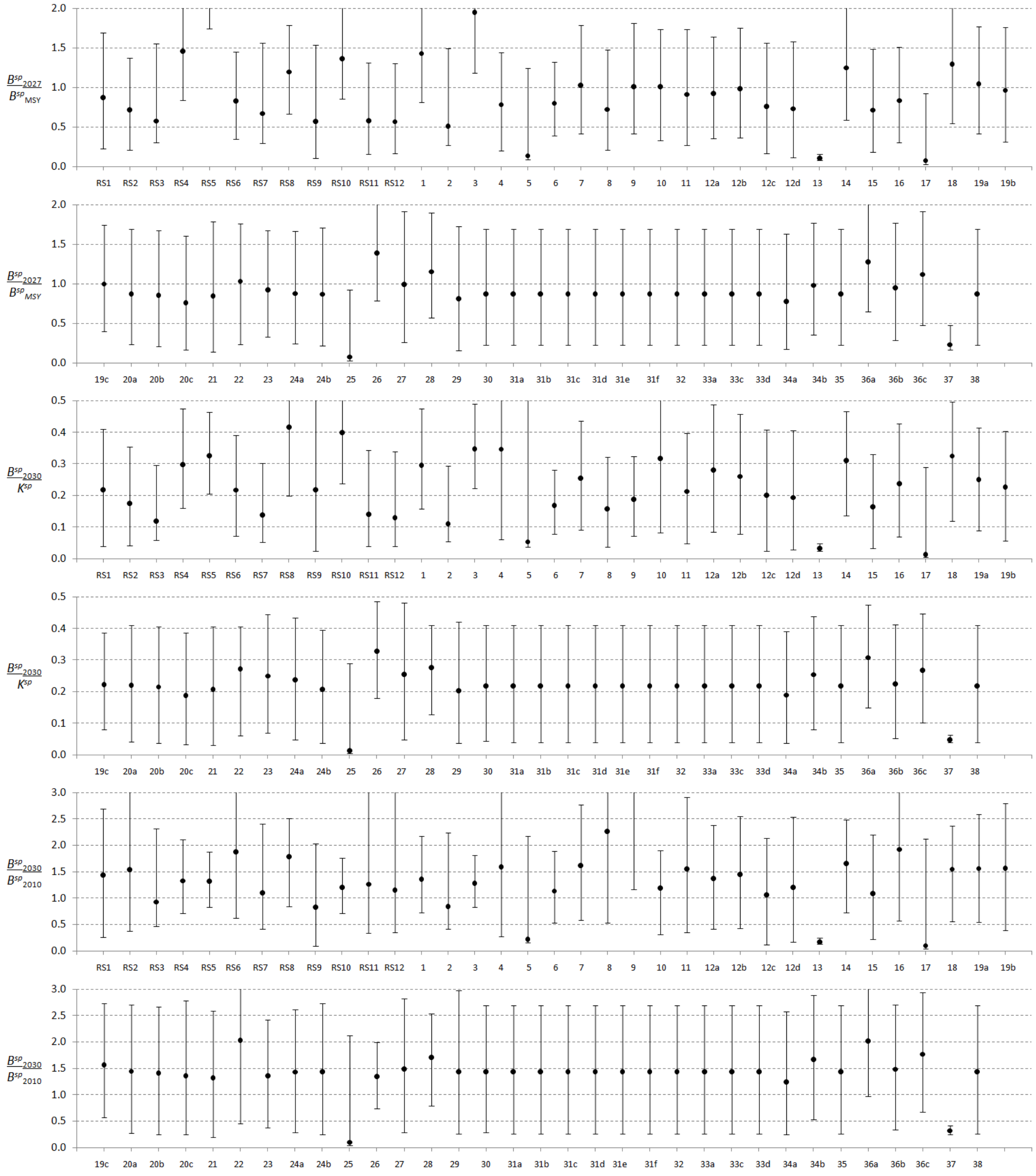


Figure 9.8a: Three performance statistics ($B^{sp}_{2027}/B^{sp}_{MSY}, B^{sp}_{2030}/K^{sp}$ and $B^{sp}_{2030}/B^{sp}_{2010}$, in terms of female biomass only) for *M. paradoxus* for the full set of RS and robustness tests under a projected constant catch of 150 000t. In some instance, the statistics are outside the area covered by the plot.

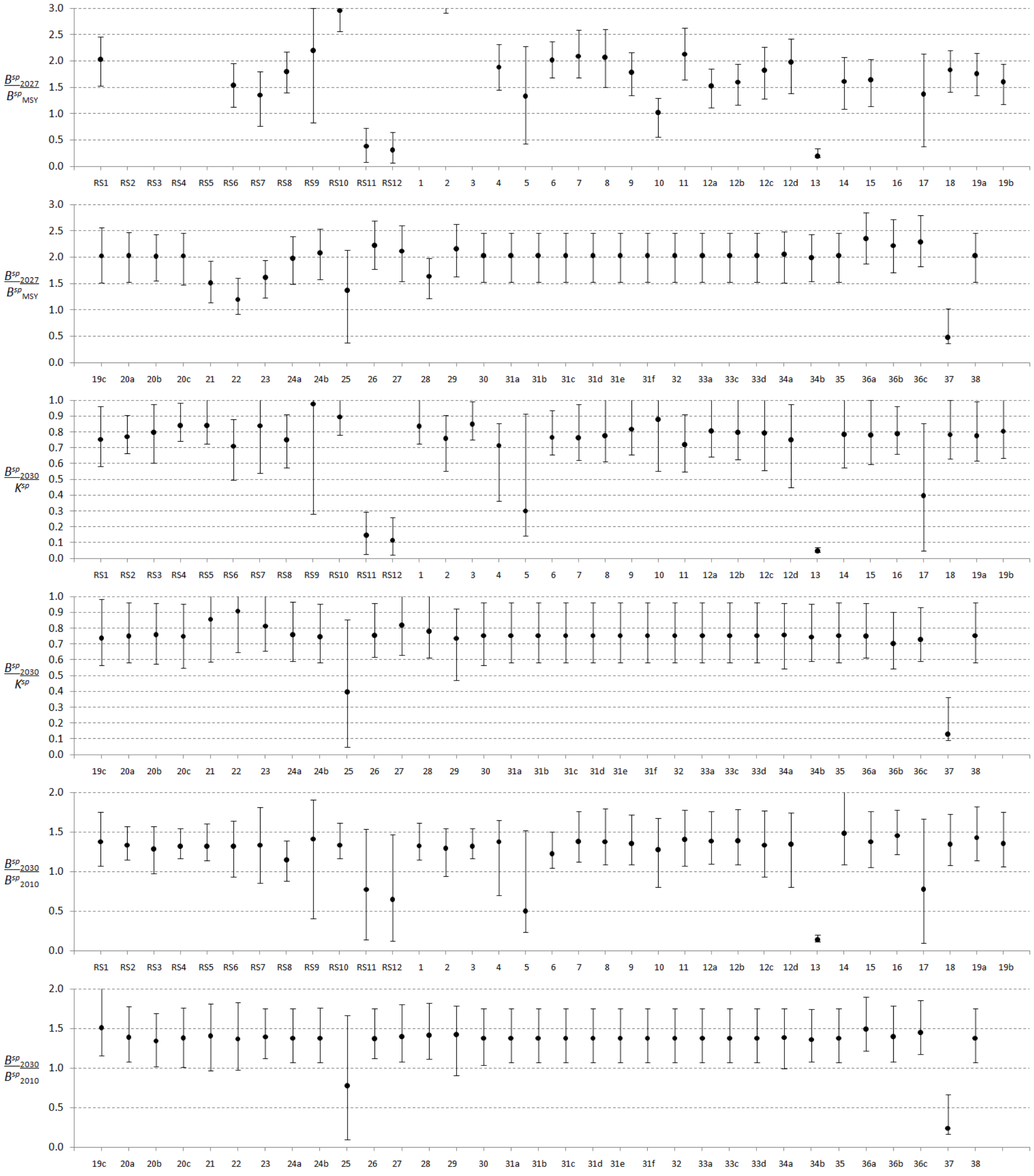


Figure 9.8b: Three performance statistics ($B^{sp}_{2027}/B^{sp}_{MSY}, B^{sp}_{2030}/K^{sp}$ and $B^{sp}_{2030}/B^{sp}_{2010}$, in terms of female biomass only) for *M. capensis* for the full set of RS and robustness tests under a projected constant catch of 150 000t. In some instance, the statistics are outside the area covered by the plot.

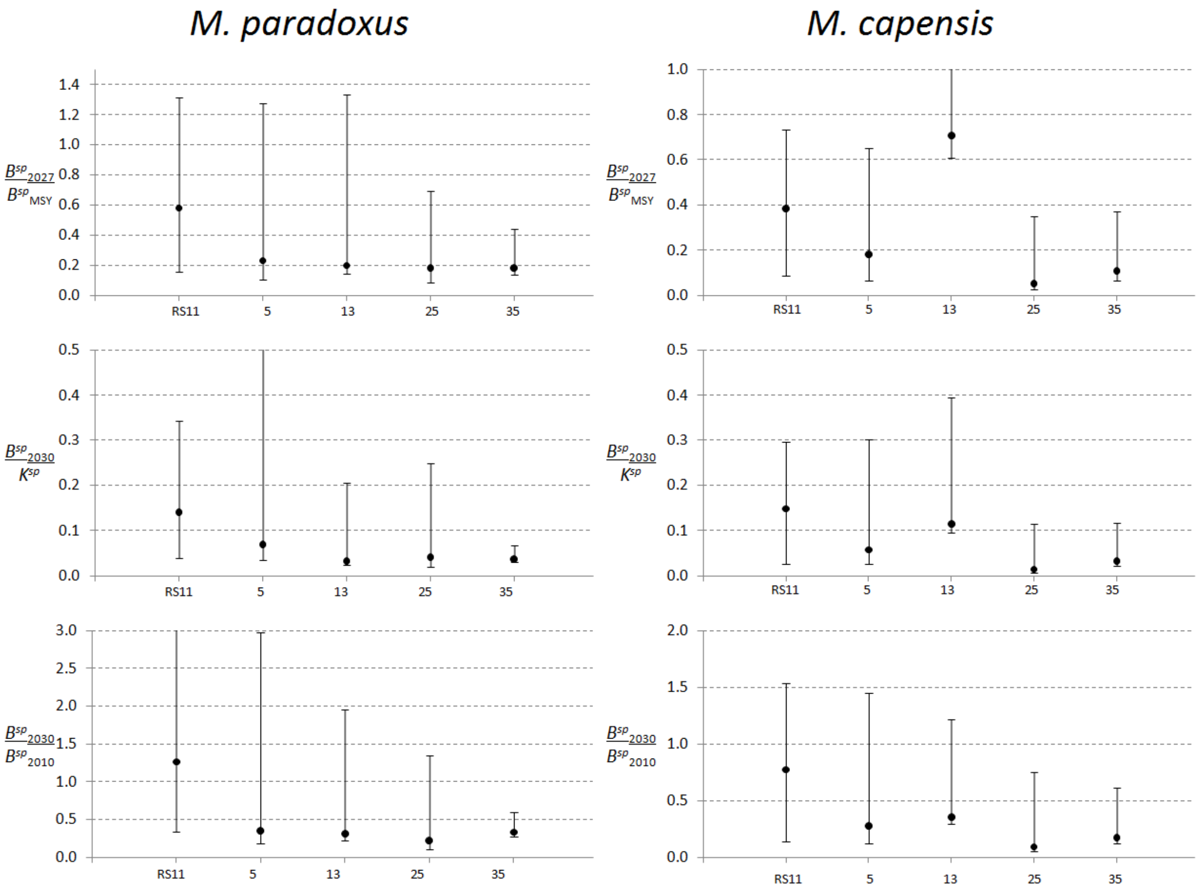


Figure 9.9 Three performance statistics ($B^{sp}_{2027}/B^{sp}_{MSY}$, $B^{sp}_{2030}/K^{sp}$ and $B^{sp}_{2030}/B^{sp}_{2010}$, in terms of female biomass only) for *M. paradoxus* and *M. capensis* for RS11 and four robustness tests based on this OM under a projected constant catch of 150 000t.

# Chapter 10

# Selecting OMP-2011

## Summary

This Chapter presents results for the anticipated performances of a series of illustrative Candidate Management Procedures (CMPs) for the South African hake resource for the Reference Set of trials. The final choice CMP (OMP-2011) to provide TAC recommendations for 2011 to 2014 is detailed, with associated results presented for the RS and a wide range of robustness tests. In making the final choice for OMP-2011 the Demersal Working Group focused on trade-offs related to i) future TACs compared to the risk of *M. paradoxus* depletion (together with subsequent recovery) for the Reference Set of trials and for the most difficult of the robustness tests (a decrease in carrying capacity *K* in the past), and also ii) the extent of inter-annual TAC variability.

## 10.1 Background

Performance statistics for a series of illustrative Candidate Management Procedures (CMPs) are evaluated for the updated Reference Set (RS) of Operating Models (OMs) as well as the associated robustness tests. The RS described in Chapter 9 consists of two parts: the primary RSa of ten OMs for which, even though there has been a decline over recent years, the current status of *M. capensis* remains above MSYL in nearly all cases and is not a concern, and RSb which comprises two OMs for which *M. capensis* is well below MSYL.

Any OMP revision exercise has to be closely linked to the objectives for the management of the resource. The objectives for the hake OMP adopted in 2006 were (see Chapter 5):

a) Improve catch rates in the short term, considered operationally as increasing the expected CPUE for the offshore trawlers by 50% over its average for the 2003-2005 period by 2016.

b) Limit inter-annual TAC variations, with an operational implementation that these not exceed 10% p.a.

c) Recover the *M. paradoxus* resource, taken operationally to mean to reach its MSYL ($B^{sp}_{MSY}$) by 2027.

d) Have a low probability of further decline in the *M. paradoxus* resource, taken operationally to mean that the lower 2.5%-ile of the *M. paradoxus* spawning biomass should be above the corresponding 2007 level in 2027.

These objectives were reviewed in discussions amongst stakeholders. The re-certification of the hake trawl fishery by the MSC was granted in March 2010 with a condition regarding certain aspects of the OMP revision process. In revising the objectives set for OMP-2007, some of the requirements for continued MSC certification had therefore to be taken into account.

a) In the re-certification exercise, the certification team emphasised the importance that recovery targets not be extended in time (MSC officials had also expressed concern about the length of the 20-year period set for the recovery of *M. paradoxus* to its MSYL in 2006).

b) A condition was attached to the re-certification (MSC 2010c):

> **Condition 7. Appropriate limit and target reference points for *M. paradoxus* based on stock biomass and/or fishing mortality**
>
> **Action required:** The limit reference point is the lower 95% confidence interval of the recovery trajectory in the 2006 OMP meaning the limit reference point is not a constant, but a level that will vary over time. At its lowest point, a *M. paradoxus* spawning biomass might not be low enough to trigger management override of the default OMP response, risking recruitment failure.
> SG 80 states: 'Limit and target/precautionary reference points should be justified based on stock biology (e.g. a stock-recruitment relationship) and measurable given data and assessment limitations. Reference points may be probability based'.
> It is anticipated that the OMP will undergo revision during 2010. This condition could be addressed within this planning process and thereby formally linked to the harvest control rules (OMP) that will be used to set TACs for the period of certification. The OMP revision process in 2010 should explicitly consider limit control rules with that planning evaluation.
>
> **Timescale:** Appropriate limit and target reference points enacted within one year of certification.

c) Cognisance needed to be taken of the continuing development of MSC conditions for certification. In future re-certification processes these may well include requirements along the lines of:
    i) a high probability of being above the abundance where recruitment success may be impaired (essentially synonymous with the limit reference point concept), and
    ii) where the resource is below its MSYL, recovery to MSYL should be targeted for a multiple (possibly a number in the range [2; 3]) of the time it would take to reach that level in the absence of any catches.

## 10.2 Operational Objectives

The MSC's particular focus has been on the status of *M. paradoxus* in terms of biomass. The following Reference Points (defined in terms of the RSa set of operating models) were therefore included in the operational objectives:

- Target Reference Point: $B^{sp}_{\text{MSY}}$
- Limit Reference Point: $B^{sp}_{2007}$ (a low point on the past biomass trajectory)

The following operational objectives were used for guidance in developing CMPs to replace OMP-2007.

a) *M. paradoxus* recovery to the Maximum Sustainable Yield (MSY) level (in terms of the median under the Reference Set of operating models) should be no slower than intended under OMP-2007, and ideally should occur within a period of 2 to 3 times what would be realised in the absence of any exploitation (this MSY level - $B^{sp}_{\text{MSY}}$ - is the Target Reference Point required to be specified under the MSC re-certification).

b) The lower 2.5%ile for the spawning biomass of *M. paradoxus* should not decrease below the 2007 level estimated by the Reference Set of models ($B^{sp}_{2007}$ - this is the Limit Reference Point required by the MSC re-certification).

c) The lower 2.5%ile for the lowest TAC anticipated should be as high as possible for socio-economic reasons.

d) Inter-annual increases in TAC should not exceed 10% while decreases should not exceed 5% (to facilitate stability in the industry), except in circumstances where catch rates fall below specified threshold levels.

## 10.3 Candidate Management Procedures Testing Methodology

CMP testing is based on the simulated application of some feedback harvest control rule to different Operating Models (OMs) of the resource. It requires projections of the resource's dynamics into the future, so as to be able to simulate the impact of alternative series of future catches on the resource. Details of the projection methodology applied are provided in Appendix 10.I. The performance statistics used to compare the different CMPs are also listed in this Appendix, together with the data available to the CMPs.

## 10.4 Candidate Management Procedures investigated

A variety of Candidate Management Procedures (CMPs) has been considered. Appendix 10.II provides detailed technical specifications. All the CMPs tested have been of the "empirical" type – they use the resource monitoring data directly as input to simple formulae to provide TAC recommendations, rather than the "model-based" type which first filter these data through a (usually relatively simple) population dynamics model. Empirical procedures have been preferred, primarily because of their simplicity, which enhances the transparency and saleability of the MP (Butterworth 2008).

Results are given here only for a limited set of CMPs for illustrative purposes, although a large number of CMPs were investigated during the development of OMP-2011. Table 10.1a, lists the set of CMPs presented, with their control parameter values given in Table 10.1b. A series of steps and factors investigated in the process of selecting OMP-2011 are described below, with results for the illustrative CMPs under the Reference Set shown in Table 10.2.

### 10.4.1 Continuation of the existing OMP-2007

One option for OMP-2011 was to retain OMP-2007 for a further four years. OMP-2007 is described in detail in Chapter 5.

### 10.4.2 Simple CMPs based on biomass index trends

In the first step, simple CMPs based on biomass index trends were developed from a simplified version of OMP-2007. In CMPa132, the $\lambda$ parameter which multiples the average trend value is not time dependent, though the target increase rate parameter $T$ is decreased linearly to zero from 2020 to 2023 and fixed at zero thereafter, where 2020 is roughly the time by which MSYL for *M. paradoxus* has been reached so that TACs can be increased as production need no longer be set aside for resource growth. Other differences from OMP-2007 are the relative weightings of the CPUE and survey series in calculating average trends across biomass indices (see Section 10.4.2 below), and the use of coast-specific rather than coast-combined CPUE indices. The maximal +-10% TAC inter-annual change constraint of OMP-2007 is retained.

Results are shown in Table 10.2 and Figure 10.1 for a tuning to a median average TAC over 2011-2020 under RSa of 132 thousand tons. Figure 10.1 plots median and lower 2.5%ile projections for the TAC and for spawning biomass relative to the 2010 estimate for *M. paradoxus* for RSa, and for *M. capensis* for RSb. Table 10.3 lists the years in which each CMP sees MSYL reached. It indicates that OMP-2007 reaches MSYL (in median terms) for *M. paradoxus* in 2016, eight years earlier than estimated in 2006, which is a consequence of changed assumptions in the updated assessment together with improved survey and CPUE results over the past four years. CMPa132 also reaches MSYL at 2016, i.e. within two times the three years that would be taken if all fishing was immediately suspended. This falls within the range under consideration for possible future MSC certification requirements.

### 10.4.3 Alternative relative weightings of CPUE and survey information

OMP-2007 gave equal weighting to CPUE and survey-based biomass indices when averaging over the recent trends indicated by each to compute the trend parameter $s_y^{spp}$ to input to its TAC formula. Table 10.4 lists the weight given to the trend estimate for each biomass index in the case of equal weighting, exact inverse variance weighting and "mid-way" weighting. Inverse variance weighting relates to the precision of the trend estimates from past values of the index concerned – the caption to Table 10.4 specifies exactly how this was computed. The “mid-way” weighting is an intermediate weighting between these two “extremes”.

Three CMPs using either equal, inverse variance or "mid-way" weighting but otherwise equivalent were tuned to give the same median average annual TAC over the next decade. Of interest is the behaviour of the risk statistics, "low para" for RSa and "low cap" for RSb: an approach that sees these as high as possible would be preferred. Performance of these three CMPs under the RS (see Table 10.5) showed that the "mid-way" weighting outperforms equal weighting in terms of risk statistics ("low para"). Although inverse variance weighting performed better still, "mid-way" weighting has been chosen to be used in all other CMPs. Why not opt for inverse variance weighting? The concern is that for various reasons CPUE may not provide an exactly comparable index of biomass over time. The three CMPs have also been applied to robustness test Rob35 for which the future CPUE data generated incorporate an undetected 2% annual increase in catchability and so provide positively biased estimates of trends in biomass. Under this scenario equal weighting provides a lower risk than mid-way weighting, for which risk is in turn less than for inverse variance weighting. Considering results for both the RS and Rob35 in combination, mid-way weighting seems to provide a reasonable compromise.

### 10.4.4 Include adjustments based on a target CPUE and survey value

A modification to the structure of the TAC formula for OMP-2007 and CMPa132 was investigated where in addition to recent trends in indices of biomass, the TAC is also varied in relation to how CPUE and surveys averaged over three recent years compare to a target CPUE and survey level. For CMPb132, the TAC is then adjusted up or down by an amount proportional to how far the recent biomass indices are above or below the chosen target level (see equation App.10.II.3).

Tables 10.2 and 10.3 as well as Figure 10.1 show results for CMPb132, with the tuning to a median average catch of 132 thousand tons over the next decade under RSa, as for CMPa132.

The attractive feature of CMPb132 results is the reduced range of TAC values to be expected (see Figure 10.1). Thus comparing CMPa132 and CMPb132, the latter reflects a lower 2.5%ile for the annual TAC that is more than 10 thousand tons greater than for the former. Risk in terms of "low para" under RSa is also slightly reduced (Table 10.2). However, these desirable features are achieved at the expense of a likely lesser increase and further a substantial probability of an appreciable decrease in the TAC over the next few years (Figure 10.1), which are not an attractive prospect for industry.

CMPc132 is an amalgamation of CMPa132 ("slope only") and CMPb132 ("slope+target") which seeks to retain the desirable but exclude the less desirable features of the two approaches by using the first for the first two years and then phasing linearly to the second over the next three.

Results for this phasing approach are shown in Table 10.2 and Figure 10.1, and indicate that it has eliminated the undesirable features of CMPa132's and CMPb132's behaviours.

### 10.4.5 Further penalty

Although the final one or two CMPs are checked on the complete suite of robustness tests, only a selected subset of robustness tests were used to test the CMPs routinely. To reduce the number of robustness tests to be run routinely for the CMPs, the ones that appear under constant catch projections to present the greatest challenges from a resource conservation perspective were selected to form a key set of robustness tests. A projected constant catch of 150 000t was chosen as this is more informative (in terms of the poor resource conservation performers) than a constant catch set at the current TAC.

In terms of the tests related to *M. paradoxus*, the following robustness tests were retained: for changes in the past: robustness tests Rob5 (true Ricker), Rob13 (decrease in *K*), Rob17 (start in 1978) and Rob25 (lower steepness *h*) and for changes in the future robustness tests Rob31f (case of no future surveys and an undetected catchability trend for CPUE), Rob35 (undetected catchability trend for CPUE) and Rob37 (decrease in *K*). With the exception of tests Rob31f and Rob35 for which constant catch trials do not provide a test of the variation involved, the reason for these selections is inadequate increase of spawning biomass towards its MSY level.

Robustness tests are also needed for the case when the extent of *M. capensis* depletion is estimated to be relatively high (RSb) and four robustness tests were selected to be run on RS11 (on of the RSb OMs). For changes in the past, three of the four robustness tests selected for *M. paradoxus* testing above were chosen (Rob5, Rob13 and Rob25, but not Rob17 which is of a different nature and does not show *M. capensis* to be heavily depleted), and for changes in the future, Rob37 (decrease in *K*) was selected.

This key set of more severe robustness tests were run under CMPc132, with the results shown in Table 10.6. Because this CMP does not perform well in some of these tests, an extra "safeguard" rule was added if the CPUE and surveys fall below a fixed level. Specifically the TAC is further reduced by a penalty if recent average biomass indices falls below their average value over 2006-2008, with the size of the reduction related to the magnitude of the shortfall (see Appendix 10.II for details). Furthermore, the constraint on the maximum inter-annual TAC change is loosened if the biomass indices fall too low. This is in the spirit of a limit reference point approach where additional conservation measures are taken if resource biomass drops below a specified threshold, and was investigated here as a response to the MSC's re-certification condition 7. The CMP with these further penalties is referred to as CMPd132.

The values of the control parameters ($p^{spp}$ and $Q_{min}$ - see Appendix 10.II) were chosen to secure a minimal effect on performance under the RS, with their impacts coming into play only at CPUE and survey values below the range expected under the RS.

Figure 10.2 focuses on test Rob13 (decrease in *K* in the past) which led to the worst performance of all in terms to *M. paradoxus* depletion under CMPc132. The lower 2.5%ile envelope for *M. paradoxus* spawning biomass, which shows continuous decline under CMPc132, has this decline reversed under CMPd132. As also evident from these same Tables and Figure, these modifications to CMPc132 hardly alter its performance under RSa, as intended.

For the other more severe robustness tests for *M. paradoxus*, changing from CMPc132 to CMPd132 improves the depletion level for *M. paradoxus* for Rob17 (start in 1978) and for Rob25 (lower steepness *h*), and also improves performance for Rob37 (future decrease in *K*) (see Table 10.6). It has little impact on Rob31f (no future surveys and an undetected catchability trend for CPUE in the future), which is not too surprising as in the absence of future surveys, the misleading upward bias in CPUE prevents the adjustment of equation App.10.II.3 coming into play.

This change from CMPc132 to CMPd132 also secures some improvement in risk-related statistics for *M. capensis* for more severe robustness tests related to RSb (see Table 10.6b).

### 10.4.6 TAC inter-annual change constraints

Table 10.2 shows results for CMPe132 which decreases the downward TAC change constraint to 5% (from 10%). The upward constraint remains unchanged and the loosening of the constraints if the CPUE falls too low (described above) is retained. These results indicate that the restriction of annual TAC downward changes to 10% could be reduced to 5% without compromising resource risk.

### 10.4.7 Tuning

To illustrate the medium-term catch *vs* recovery trade-off, three tunings were selected corresponding to median average annual TACs over the next 10 years of 127, 132 and 137 000t, corresponding in Table 10.2 to CMPe127, CMPe132 and CMPe137 respectively. Note that continued application of the existing OMP-2007 would achieve a median average annual catch of 127.4 thousand tons over the next decade (see Table 10.2).

### 10.4.8 Other options explored

The effect of an increase in the $\lambda$ parameter multiplying average trend values in the TAC formula was investigated. The risk to the resource increased together with a substantial rise in the average annual TAC variation, so that this option was not considered further.

In the CMPs described above, the next year's TAC is based on the previous year's TAC. This approach was compared to basing next year's TAC on the average TAC over the last five years instead. Although this approach offered some advantages in terms of raising the lower 2.5%ile for future TACs (reducing variability), this was more than offset by higher risk, coupled to a median TAC trajectory that first increased and then declined over the next few years.

The imposition of a TAC cap of 160 000t was also considered but it did not provide any further risk benefits, so that this option was not pursued further.

## 10.5 Final OMP-2011 selection

The development of OMP-2011 involved regular consultation with stakeholders, including scientists, resource managers, industry representatives, as well as representatives of the Marine Stewardship Council. From the wide range of CMPs tested and described above, a final set of six CMPs was selected, varying along two axes: a) the level of inter-annual TAC change constraints (+10%/-10% and +10%/-5%; i.e. CMPd *vs* CMPe) and b) the median projected TAC over the next decade (127, 132 and 137 000t; i.e. CMPd/e127 *vs* 132 *vs* 137). These two axes summarise two trade-offs: the trade-off between higher TACs and higher risk of *M. paradoxus* depletion, and the trade-off in relation to inter-annual TAC variation.

### 10.5.1 Reference Set

Results for these six final CMPs are given in Table 10.2 for the RS. Medians and lower 2.5%iles for the TAC and for $B^{sp}/B^{sp}_{2010}$ for *M. paradoxus* under RSa are compared in Figure 10.2. Figures 10.3a-f plot a large number of projection statistics for each of the six CMPs, with Figure 10.3g contrasting the levels of inter-annual TAC variation to be expected under the six CMPs.

Figure 10.4 plots medians and lower 2.5%iles of $B^{sp}/B^{sp}_{MSY}$ for *M. paradoxus* under RSa of which consideration needs to be taken in the context of satisfying MSC-related recovery requirements. Figure 10.5 compares medians and 95%iles for a series of performance statistics under the six CMPs for the RS.

### 10.5.2 Robustness tests

The full set of robustness tests are listed in Chapter 9. Results for CMPe137 under this full set are given in Table 10.7, and medians and 95%iles for a series of performance statistics are plotted in Figure 10.6. Only the least conservative of the six CMPs (CMPe137) has been tested against the full set, because the other candidates would show better risk-related performances. What stands out from the comparisons in Figure 10.6 for RSa-related tests is that the risk in terms of unintended depletion of *M. paradoxus* to a low spawning biomass is much higher for test Rob13 (a decrease in *K* in the past) than for any of the other tests. This is confirmed in the Figure 7 plots of medians and lower 2.5%iles for the TAC and for $B^{sp}/B^{sp}_{2010}$ for *M. paradoxus* for the seven most difficult of these tests based on the RC. It is only for Rob13 that there is any appreciable reduction at the lower 2.5%ile below the 2007 minimum spawning biomass for *M. paradoxus*.

For the RSb-related robustness tests (*M. capensis* in need of rebuilding) for which medians and lower 2.5%iles for the TAC and for $B^{sp}/B^{sp}_{2010}$ for *M. capensis* are shown in Figure 10.8, median recovery rates for *M. capensis* are slow, but perhaps of most importance is that again there is scarcely any probability at the lower 2.5%ile of dropping below the 2007 spawning biomass minimum.

### 10.5.3 OMP-2011

In term of the inter-annual TAC variations, the stakeholders agreed on the 5% maximum downward inter-annual TAC constraint option, except in circumstances where the relevant composite biomass index falls below a threshold level in which case this maximum downward constraint could be as high as 25%. Results were judged to indicate that the larger downward constraint of 10% offered no real benefits to the resource in conservation terms, while exposing industry to greater potential socio-economic instability.

The trade-off between higher TACs and higher risk of *M. paradoxus* depletion is illustrated in Figure 10.1c at the lower 2.5%ile in relation to the *M. paradoxus* spawning biomass dropping below its current 2010 level under the RS. Figure 10.4 shows similar plots in terms of recovery to the MSY level for spawning biomass. The stakeholders agreed that the least conservative option (a median projected TAC of 137 000t over the next decade) showed inadequate recovery of *M. paradoxus* in the context of satisfying MSC-related recovery requirements for certification.

CMPe132, with a median projected TAC of 132 000 tons over the next decade, was accepted for recommendation as OMP-2011 as it was seen to reflect an appropriate compromise between speed of recovery and utilisation of the resource during that recovery period.

### 10.5.4 Exceptional Circumstances

Implicit in the OMP development process is the adoption of an "Exceptional Circumstances" protocol to cover situations outside the range for which the OMP was simulation tested. This document, developed by the Demersal Scientific Working Group, is reproduced in Appendix 10.III.

Unless an Exceptional Circumstance is triggered, the application of OMP-2011 will provide TAC recommendations for the period 2011-2014.

### 10.5.5 2011 TAC Recommendation

The 2011 TAC recommendation for the South African hake resource was computed in terms of the OMP-2011 (Appendix 10.II) as follows:

$$C_y^{spp} = w_y C_{y-1}^{*spp}\left[1 + \lambda_{up/down}\left(s_y^{spp} - T_y^{spp}\right)\right] + \left(1 - w_y\right)\left[a^{spp} + b^{spp}\left(J_y^{spp} - 1\right) - Pen_y^{spp}\right]$$

(10.1)

The computations input a TAC of 119 800 thousand tons for 2010. As specified in the OMP, this is disaggregated by species assuming the 2009 species-split of the catches, i.e. 80.12% (95 985 tons) *M. paradoxus* and 19.88% (23 815 tons) *M. capensis* to provide the $C_{y-1}^{*spp}$ values for equation (10.1).

The GLM-standardised CPUE series (Glazer 2010) and survey biomass estimates (Fairweather and Sithole 2010) used as inputs to the OMP are shown in Table 10.7 and the resulting trends in Figure 10.10. Note that the results from surveys carried out with the *Africana* with new gear have been rescaled to take the calibration factor into account (this involves dividing new gear estimates by 0.95 for *M. paradoxus* and 0.80 for *M. capensis*), as specified in the OMP.

The recent annual trend, $s_y$, computed from a specified weighted average of the CPUE and survey slopes, is 10.98 % for *M. paradoxus* and 8.68% for *M. capensis*. Since $w_{2011} = 1$ and $T_{2011}^{para} = 0.75\%$, the *M. paradoxus* contribution to the TAC is:

$$C_{2012}^{para} = 95985t[1 + 1.25(10.98\% - 0.75\%)] = 108258t$$

and the *M. capensis* contribution:

$$C_{2010}^{cap} = 23815t[1 + 1.25(8.68\% - 0\%)] = 26400t$$

The resulting value from these computations is a TAC of 134 658 tons. Due to the constraint that the TAC cannot increase by more than 10% from one year to the next, the final TAC that was recommended for 2011 was 131 780 (i.e. an increase of 10% from the 2010 level of 119 800t).

Table 10.1a: Summary of an illustrative set of CMPs.

| CMP | Description | Tuned to average catch over 2011-2020 | Inter-annual change constraints |
|---|---|---|---|
| OMP-2007 | Slope-based only, see Appendix 5.I for details | | |
| CMPa132 | Slope-based only | 132 000t | 10%-10% |
| CMPb132 | Slope- + target-based | 132 000t | 10%-10% |
| CMPc132 | Phasing from slope-based only to slop- + target-based | 132 000t | 10%-10% |
| CMPd127 | As CMPc132 but with extra penalty | 127 000t | 10%-10% |
| CMPd132 | As CMPc132 but with extra penalty | 132 000t | 10%-10% |
| CMPd137 | As CMPc132 but with extra penalty | 137 000t | 10%-10% |
| CMPe127 | As CMPd132 | 127 000t | 10%-5% |
| CMPe132 | As CMPd132 | 132 000t | 10%-5% |
| CMPe137 | As CMPd132 | 137 000t | 10%-5% |

Table 10.1b: Tuning parameter values for each CMP for which performance statistics are presented. $T^{para}$ applies up to the year 2015 and then declines linearly to zero in year 2018, except for OMP-2007, for which $T^{para}$ applies to the whole projection period.

| CMP | $\lambda_{up}$ | $\lambda_{down}$ | $T^{para}$ | $T^{cap}$ | $w$ | $a^{para}$ | $a^{cap}$ | $b^{para}$ | $b^{cap}$ | $c^{para}$ | $c^{cap}$ | $p^{para}$ | $p^{cap}$ | $Q_{min}$ | Annual change constraints | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| OMP-2007 | 0.4-1.1* | 1.1-2.0* | 1.83% | 0 | - | - | - | - | - | - | - | - | - | - | +10% | -10% |
| CMPa132 | 1.25 | 1.50 | 2.19% | 0 | - | - | - | - | - | - | - | - | - | - | +10% | -10% |
| CMPb132 | 1.25 | 1.50 | 2.19% | 0 | 0.5 | 114.8 | 40 | 95 | 30 | - | - | - | - | - | +10% | -10% |
| CMPc132 | 1.25 | 1.50 | 1.00% | 0 | 1-0.5 | 99.5 | 40 | 60 | 20 | - | - | - | - | - | +10% | -10% |
| CMPd127 | 1.25 | 1.50 | 1.00% | 0 | 1-0.5 | 96.2 | 40 | 60 | 20 | 180 | 20 | 0.75 | 0.75 | 0.75 | +10% | -10%** |
| CMPd132 | 1.25 | 1.50 | 0.75% | 0 | 1-0.5 | 105.8 | 40 | 60 | 20 | 180 | 20 | 0.75 | 0.75 | 0.75 | +10% | -10%** |
| CMPd137 | 1.25 | 1.50 | 0.50% | 0 | 1-0.5 | 115.4 | 40 | 60 | 20 | 180 | 20 | 0.75 | 0.75 | 0.75 | +10% | -10%** |
| CMPe127 | 1.25 | 1.50 | 1.00% | 0 | 1-0.5 | 94.7 | 40 | 60 | 20 | 180 | 20 | 0.75 | 0.75 | 0.75 | +10% | -5%** |
| CMPe132 | 1.25 | 1.50 | 0.75% | 0 | 1-0.5 | 104.5 | 40 | 60 | 20 | 180 | 20 | 0.75 | 0.75 | 0.75 | +10% | -5%** |
| CMPe137 | 1.25 | 1.50 | 0.50% | 0 | 1-0.5 | 114.3 | 40 | 60 | 20 | 180 | 20 | 0.75 | 0.75 | 0.75 | +10% | -5%** |

* see Appendix 5.I for details.

** can change up to -25% following equation App.10.II.12.

Table 10.2: Projections results (either median, lower or upper 2.5%ile) for a series of performance statistics for an illustrative set of CMPs under the RS. Catch units are thousand tons. The "low para $B^{sp}_{low}/B^{sp}_{2010}$" cells are shaded if values are less than 0.76 (the 2007 level); the "lowest TAC (2011-2030)" cells are shaded if less than 95 (thousand tons).

| | | RSa | OMP-2007 | CMPa132 | CMPb132 | CMPc132 | CMPd127 | CMPd132 | CMPd137 | CMPe127 | CMPe132 | CMPe137 |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| median | BS | avC: 2011-2020 | 127.4 | 132.0 | 132.0 | 132.0 | 127.0 | 132.0 | 137.0 | 127.0 | 132.0 | 137.0 |
| low | para | $B^{sp}_{low}/B^{sp}_{2010}$ | 0.72 | 0.72 | 0.75 | 0.73 | 0.73 | 0.72 | 0.71 | 0.73 | 0.72 | 0.71 |
| low | cap | $B^{sp}_{low}/B^{sp}_{2010}$ | 0.72 | 0.73 | 0.71 | 0.76 | 0.78 | 0.78 | 0.77 | 0.78 | 0.77 | 0.75 |
| median | para | $B^{sp}_{2020}/B_{MSY}$ | 1.30 | 1.19 | 1.20 | 1.18 | 1.29 | 1.19 | 1.10 | 1.29 | 1.20 | 1.11 |
| median | cap | $B^{sp}_{2020}/B_{MSY}$ | 2.93 | 2.91 | 2.91 | 2.90 | 2.93 | 2.89 | 2.87 | 2.93 | 2.90 | 2.87 |
| median | BS | AAV | 4.2 | 4.6 | 4.2 | 3.4 | 3.7 | 3.7 | 3.8 | 3.5 | 3.5 | 3.6 |
| low | BS | lowest TAC (2011-2030) | 88.7 | 86.6 | 98.4 | 101.0 | 89.7 | 94.9 | 99.7 | 87.8 | 91.9 | 94.5 |
| | BS | Prob decl >20% (2011-2013) | 2.6 | 1.6 | 0.4 | 0.9 | 0.2 | 0.2 | 0.1 | 1.5 | 1.5 | 1.3 |
| | BS | Prob decl >20% (2012-2014) | 4.4 | 5.0 | 0.0 | 0.6 | 1.1 | 1.2 | 1.0 | 1.6 | 1.4 | 1.4 |
| median | BS | Pdecl>20% (2011-2028) | 0.0 | 5.6 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 |
| high | BS | Pdecl>20% (2011-2028) | 16.7 | 27.8 | 16.7 | 11.1 | 0.0 | 0.1 | 5.6 | 5.6 | 5.6 | 5.6 |
| | | RSb | | | | | | | | | | |
| median | BS | avC: 2011-2015 | 122.0 | 125.1 | 126.3 | 126.8 | 121.8 | 126.7 | 131.6 | 120.6 | 125.6 | 130.5 |
| low | para | $B^{sp}_{low}/B^{sp}_{2010}$ | 0.95 | 0.94 | 0.95 | 0.93 | 0.93 | 0.93 | 0.93 | 0.93 | 0.93 | 0.93 |
| low | cap | $B^{sp}_{low}/B^{sp}_{2010}$ | 0.88 | 0.85 | 0.88 | 0.84 | 0.87 | 0.84 | 0.80 | 0.87 | 0.85 | 0.80 |
| median | para | $B^{sp}_{2020}/B_{MSY}$ | 1.04 | 0.97 | 1.00 | 0.94 | 1.00 | 0.95 | 0.88 | 1.04 | 0.96 | 0.89 |
| median | cap | $B^{sp}_{2020}/B_{MSY}$ | 0.60 | 0.58 | 0.58 | 0.56 | 0.58 | 0.56 | 0.54 | 0.60 | 0.57 | 0.55 |
| median | BS | AAV | 4.3 | 4.3 | 3.9 | 3.2 | 3.6 | 3.4 | 3.4 | 3.6 | 3.4 | 3.5 |
| low | BS | lowest TAC (2011-2030) | 87.1 | 88.8 | 97.5 | 100.0 | 84.2 | 87.7 | 99.4 | 75.3 | 84.5 | 86.1 |
| | BS | Prob decl >20% (2011-2013) | 3.0 | 2.5 | 1.0 | 1.0 | 1.0 | 0.0 | 0.0 | 3.5 | 3.5 | 3.0 |
| | BS | Prob decl >20% (2012-2014) | 10.5 | 10.0 | 0.0 | 2.5 | 2.0 | 2.0 | 2.0 | 9.0 | 7.0 | 3.0 |
| median | BS | Pdecl>20% (2011-2028) | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 |
| high | BS | Pdecl>20% (2011-2028) | 16.7 | 22.2 | 16.7 | 11.1 | 5.6 | 5.6 | 5.6 | 11.1 | 11.1 | 5.6 |

Table 10.3: Year in which the *M. paradoxus* spawning biomass is expected (in median terms) to first exceed $B_{MSY}$ for a catch of zero and a series of CMPs for RSa. OMP-2007* is as applied in 2006 (i.e. to the 2006 RS), while OMP-2007 has been run under the current RSa.

| CMP | Year *M. paradoxus* spawning biomass $> B_{MSY}$ |
|---|---|
| Catch = 0 | 2013 |
| OMP-2007* | 2024 |
| OMP-2007 | 2016 |
| CMPa132 | 2016 |
| CMPb132 | 2015 |
| CMPc132 | 2015 |
| CMPd132 | 2017 |
| CMPe127 | 2016 |
| CMPe132 | 2017 |
| CMPe137 | 2017 |

Table 10.4: Weighting of the CPUE and survey series when computing $s_y^{spp}$, the measure of immediate past trend in the biomass indices. The variances for the various trend estimates were obtained from empirical estimates of variance for the slope in the log-linear fit of a trend to five successive points of the series in question. An average was taken over five such estimates: that for the most recent 5 years, and for CPUE those for such periods set earlier by one, two, three of four years. For surveys the set back was only up to three years for the West Coast, and two years for the South Coast, because of years without *Africana* surveys in the early 2000s.

| | | Equal Weigthing | Inverse variance weighting | Mid-way weighting |
|---|---|---|---|---|
| **CPUE** | | | | |
| *M. paradoxus* | WC | 1.00 | 1.00 | 1.00 |
| | SC | 1.00 | 0.40 | 0.75 |
| *M. capensis* | WC | 1.00 | 1.00 | 1.00 |
| | SC | 1.00 | 0.40 | 0.75 |
| **Survey** | | | | |
| *M. paradoxus* | WC | 1.00 | 0.20 | 0.50 |
| | SC | 1.00 | 0.02 | 0.25 |
| *M. capensis* | WC | 1.00 | 0.20 | 0.50 |
| | SC | 1.00 | 1.00 | 1.00 |

Table 10.5: Projection results for a series of performance statistics for CMPa132, CMPa132 with equal weighting of the CPUE and survey series in the slope calculation ("equal weighting") and CMPa132 with exact inverse variance weighting ("inverse variance weighting"). These results are presented for the RS and Rob35 (undetected 2% p.a. increase in catchability related to CPUE in the future).

| | | | RS | | | Rob35 | | |
|---|---|---|---|---|---|---|---|---|
| | | **RSa** | CMPa132 | equal weighting | inverse variance weighting | CMPa132 | equal weighting | inverse variance weighting |
| median | BS | avC: 2011-2020 | 132.0 | 132.0 | 132.0 | 140.6 | 139.3 | 143.1 |
| low | para | $B^{sp}_{low}/B^{sp}_{2010}$ | 0.72 | 0.70 | 0.73 | 0.76 | 0.77 | 0.68 |
| low | cap | $B^{sp}_{low}/B^{sp}_{2010}$ | 0.73 | 0.73 | 0.74 | 0.94 | 0.95 | 0.95 |
| median | para | $B^{sp}_{2020}/B_{MSY}$ | 1.19 | 1.20 | 1.17 | 1.02 | 1.05 | 0.98 |
| median | cap | $B^{sp}_{2020}/B_{MSY}$ | 2.91 | 2.89 | 2.89 | 2.38 | 2.41 | 2.36 |
| median | BS | AAV | 4.6 | 5.0 | 4.4 | 4.7 | 5.2 | 4.7 |
| low | BS | lowest TAC (2011-2030) | 86.6 | 85.5 | 85.9 | 99.7 | 95.8 | 100.3 |
| | BS | Prob decl >20% (2011-2013) | 1.6 | 2.5 | 1.4 | 0.0 | 0.0 | 0.0 |
| | BS | Prob decl >20% (2012-2014) | 5.0 | 6.0 | 3.4 | 0.0 | 0.0 | 0.0 |
| median | BS | Pdecl>20% (2011-2028) | 5.6 | 5.6 | 0.0 | 0.0 | 0.0 | 0.0 |
| high | BS | Pdecl>20% (2011-2028) | 27.8 | 27.8 | 27.8 | 0.0 | 0.0 | 0.0 |
| | | **RSb** | | | | | | |
| median | BS | avC: 2011-2015 | 125.1 | 124.9 | 126.4 | | | |
| low | para | $B^{sp}_{low}/B^{sp}_{2010}$ | 0.94 | 0.94 | 0.93 | | | |
| low | cap | $B^{sp}_{low}/B^{sp}_{2010}$ | 0.85 | 0.85 | 0.86 | | | |
| median | para | $B^{sp}_{2020}/B_{MSY}$ | 0.97 | 0.99 | 0.93 | | | |
| median | cap | $B^{sp}_{2020}/B_{MSY}$ | 0.58 | 0.58 | 0.57 | | | |
| median | BS | AAV | 4.3 | 4.9 | 4.2 | | | |
| low | BS | lowest TAC (2011-2030) | 88.8 | 85.9 | 91.5 | | | |
| | BS | Prob decl >20% (2011-2013) | 2.5 | 3.0 | 1.0 | | | |
| | BS | Prob decl >20% (2012-2014) | 10.0 | 12.5 | 5.0 | | | |
| median | BS | Pdecl>20% (2011-2028) | 0.0 | 0.0 | 0.0 | | | |
| high | BS | Pdecl>20% (2011-2028) | 22.2 | 16.7 | 22.2 | | | |

Table 10.6a: Projections results (either median or lower 2.5%ile: "low") for a series of performance statistics for CMPc132 and CMPd132 for a series of more severe robustness tests related to *M. paradoxus* (Rob5 (true Ricker), Rob13 (decrease in *K* in the past), Rob17 (start in 1978), Rob25 (lower steepness *h*), Rob31f (case of no survey and an undetected catchability trend for CPUE in the future - the surveys are used in the computation of the slope until more than two data points (out of six) are missing for the regression.), Rob35 (undetected catchability trend for CPUE in the future) and Rob37 (future decrease in *K*)) under RS1 and RSa.

| | | | Based on RS1 only | | | | | Based on Rsa | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| | | **CMPc132** | RS1 | Rob5 | Rob13 | Rob17 | Rob25 | RSa | Rob31f | Rob35 | Rob37 |
| median | BS | avC: 2011-2020 | 134.0 | 127.8 | 99.8 | 104.0 | 115.1 | 132.0 | 140.2 | 137.2 | 131.1 |
| low | para | $B^{sp}_{low}/B^{sp}_{2010}$ | 0.85 | 0.71 | 0.00 | 0.18 | 0.40 | 0.73 | 0.63 | 0.70 | 0.48 |
| low | cap | $B^{sp}_{low}/B^{sp}_{2010}$ | 1.02 | 0.97 | 0.06 | 0.91 | 1.07 | 0.76 | 0.74 | 0.74 | 0.35 |
| median | para | $B^{sp}_{2020}/B_{MSY}$ | 1.12 | 0.84 | 0.38 | 0.76 | 0.58 | 1.18 | 1.02 | 1.09 | 1.45 |
| median | cap | $B^{sp}_{2020}/B_{MSY}$ | 2.46 | 2.03 | 1.84 | 2.56 | 2.10 | 2.90 | 2.86 | 2.88 | 3.86 |
| median | BS | AAV | 3.3 | 3.2 | 4.5 | 5.3 | 4.0 | 3.4 | 3.7 | 3.6 | 4.0 |
| low | BS | lowest TAC (2011-2030) | 104.6 | 102.0 | 59.0 | 75.0 | 84.3 | 101.0 | 107.8 | 105.5 | 78.1 |
| | BS | Prob decl >20% (2011-2013) | 0.0 | 1.0 | 69.0 | 64.0 | 21.0 | 0.9 | 0.0 | 0.0 | 0.0 |
| | BS | Prob decl >20% (2012-2014) | 0.0 | 1.0 | 55.0 | 44.0 | 18.0 | 0.6 | 0.0 | 0.0 | 0.0 |
| median | BS | Pdecl>20% (2011-2028) | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 |
| high | BS | Pdecl>20% (2011-2028) | 11.1 | 8.5 | 0.0 | 0.0 | 14.0 | 11.1 | 0.0 | 0.0 | 11.1 |
| | | **CMPd132** | | | | | | | | | |
| median | BS | avC: 2011-2015 | 133.6 | 126.1 | 85.5 | 89.4 | 109.8 | 132.0 | 133.8 | 136.4 | 130.9 |
| low | para | $B^{sp}_{low}/B^{sp}_{2010}$ | 0.85 | 0.70 | 0.29 | 0.38 | 0.61 | 0.72 | 0.65 | 0.71 | 0.59 |
| low | cap | $B^{sp}_{low}/B^{sp}_{2010}$ | 1.03 | 0.97 | 1.02 | 0.96 | 1.07 | 0.78 | 0.79 | 0.75 | 0.36 |
| median | para | $B^{sp}_{2020}/B_{MSY}$ | 1.14 | 0.88 | 0.71 | 1.00 | 0.63 | 1.19 | 1.20 | 1.11 | 1.47 |
| median | cap | $B^{sp}_{2020}/B_{MSY}$ | 2.46 | 2.05 | 2.12 | 2.85 | 2.14 | 2.89 | 2.90 | 2.88 | 3.86 |
| median | BS | AAV | 3.5 | 3.6 | 7.4 | 7.9 | 5.0 | 3.7 | 0.6 | 3.7 | 5.0 |
| low | BS | lowest TAC (2011-2030) | 102.6 | 91.4 | 28.5 | 30.6 | 64.3 | 95.0 | 123.2 | 100.3 | 43.6 |
| | BS | Prob decl >20% (2011-2013) | 1.0 | 1.0 | 72.0 | 68.0 | 27.0 | 1.7 | 0.0 | 0.0 | 0.2 |
| | BS | Prob decl >20% (2012-2014) | 1.0 | 2.0 | 68.0 | 64.0 | 40.0 | 2.8 | 0.0 | 0.7 | 1.2 |
| median | BS | Pdecl>20% (2011-2028) | 0.0 | 0.0 | 13.9 | 11.1 | 11.1 | 0.0 | 0.0 | 0.0 | 0.0 |
| high | BS | Pdecl>20% (2011-2028) | 14.0 | 11.1 | 33.3 | 27.8 | 27.8 | 16.7 | 0.0 | 0.0 | 22.2 |

Table 10.6b: Projections results (either median or lower 2.5%ile) for a series of performance statistics for a series of more severe robustness tests under RS11 (related to *M. capensis*).

| | | | Based on RS11 only | | | | |
|---|---|---|---|---|---|---|---|
| | | **CMPc132** | RS11 | Rob5 | Rob13 | Rob25 | Rob37 |
| median | BS | avC: 2011-2020 | 127.2 | 127.4 | 104.0 | 110.8 | 125.8 |
| low | para | $B^{sp}_{low}/B^{sp}_{2010}$ | 0.93 | 1.00 | 0.18 | 0.80 | 0.84 |
| low | cap | $B^{sp}_{low}/B^{sp}_{2010}$ | 0.87 | 0.81 | 0.91 | 0.83 | 0.74 |
| median | para | $B^{sp}_{2020}/B_{MSY}$ | 0.94 | 0.84 | 0.76 | 0.69 | 1.16 |
| median | cap | $B^{sp}_{2020}/B_{MSY}$ | 0.60 | 0.54 | 2.56 | 0.48 | 0.77 |
| median | BS | AAV | 3.2 | 3.3 | 5.3 | 3.7 | 3.1 |
| low | BS | lowest TAC (2011-2030) | 100.4 | 103.9 | 75.0 | 83.2 | 88.5 |
| | BS | Prob decl >20% (2011-2013) | 1.0 | 0.0 | 64.0 | 30.0 | 0.0 |
| | BS | Prob decl >20% (2012-2014) | 2.0 | 1.0 | 44.0 | 31.0 | 0.0 |
| median | BS | Pdecl>20% (2011-2028) | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 |
| high | BS | Pdecl>20% (2011-2028) | 5.6 | 5.6 | 0.0 | 11.1 | 0.0 |
| | | **CMPd132** | | | | | |
| median | BS | avC: 2011-2015 | 126.9 | 127.7 | 89.4 | 105.6 | 125.3 |
| low | para | $B^{sp}_{low}/B^{sp}_{2010}$ | 0.93 | 1.00 | 0.38 | 0.84 | 0.88 |
| low | cap | $B^{sp}_{low}/B^{sp}_{2010}$ | 0.87 | 0.81 | 0.96 | 0.90 | 0.74 |
| median | para | $B^{sp}_{2020}/B_{MSY}$ | 0.94 | 0.83 | 1.00 | 0.71 | 1.17 |
| median | cap | $B^{sp}_{2020}/B_{MSY}$ | 0.60 | 0.54 | 2.85 | 0.50 | 0.77 |
| median | BS | AAV | 3.4 | 3.6 | 7.9 | 4.8 | 3.7 |
| low | BS | lowest TAC (2011-2030) | 88.4 | 96.6 | 30.6 | 62.9 | 74.2 |
| | BS | Prob decl >20% (2011-2013) | 2.0 | 2.0 | 68.0 | 43.0 | 0.0 |
| | BS | Prob decl >20% (2012-2014) | 6.0 | 5.0 | 64.0 | 51.0 | 2.0 |
| median | BS | Pdecl>20% (2011-2028) | 0.0 | 0.0 | 11.1 | 8.3 | 0.0 |
| high | BS | Pdecl>20% (2011-2028) | 11.1 | 11.1 | 27.8 | 22.2 | 11.1 |

Table 10.7a: Projections results (either median, lower or upper "high" 2.5%ile) for a series of performance statistics for CMPe137 under the full set of robustness tests based on the RC. The "low para $B^{sp}_{low}/B^{sp}_{2010}$" cells are shaded if values are less than 0.7 (the 2007 level); the "lowest TAC (2011-2030)" cells are shaded if less than 95 (thousand tons).

| | | | RS1 | Rob1 | Rob2 | Rob3 | Rob4 | Rob5 | Rob6 | Rob7 | Rob8 | Rob9 |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| median | BS | avC: 2011-2020 | 138.2 | 131.0 | 131.4 | 133.3 | 141.1 | 130.9 | 138.2 | 141.1 | 146.2 | 159.3 |
| low | para | $B^{sp}_{low}/B^{sp}_{2010}$ | 0.83 | 0.92 | 0.59 | 0.85 | 1.01 | 0.69 | 0.95 | 0.86 | 0.89 | 0.84 |
| low | cap | $B^{sp}_{low}/B^{sp}_{2010}$ | 0.98 | 1.02 | 1.01 | 1.00 | 1.03 | 0.96 | 0.93 | 0.99 | 0.80 | 0.82 |
| median | para | $B^{sp}_{2020}/B_{MSY}$ | 1.05 | 1.58 | 1.00 | 2.21 | 0.82 | 0.80 | 1.06 | 1.10 | 0.75 | 0.70 |
| median | cap | $B^{sp}_{2020}/B_{MSY}$ | 2.41 | 5.32 | 4.13 | 4.41 | 2.43 | 2.00 | 2.32 | 2.36 | 2.34 | 1.95 |
| median | BS | AAV | 3.5 | 3.7 | 3.6 | 3.6 | 3.4 | 3.5 | 3.3 | 3.6 | 4.2 | 4.6 |
| low | BS | lowest TAC (2011-2030) | 105.6 | 92.1 | 97.4 | 100.4 | 116.3 | 97.1 | 111.3 | 112.6 | 107.4 | 117.2 |
| | BS | Prob decl >20% (2011-2013) | 0.0 | 4.0 | 0.0 | 1.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 |
| | BS | Prob decl >20% (2012-2014) | 0.0 | 3.0 | 2.0 | 2.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 |
| median | BS | Pdecl>20% (2011-2028) | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 |
| high | BS | Pdecl>20% (2011-2028) | 0.0 | 0.1 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.1 |

| | | | RS1 | Rob10 | Rob11 | Rob12a | Rob12b | Rob12c | Rob12d | Rob13 | Rob14 | Rob15 |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| median | BS | avC: 2011-2020 | 138.2 | 142.3 | 139.8 | 135.9 | 137.6 | 139.6 | 137.8 | 87.9 | 150.7 | 131.0 |
| low | para | $B^{sp}_{low}/B^{sp}_{2010}$ | 0.83 | 0.75 | 0.88 | 0.87 | 0.85 | 0.76 | 0.80 | 0.26 | 0.80 | 0.69 |
| low | cap | $B^{sp}_{low}/B^{sp}_{2010}$ | 0.98 | 0.59 | 1.03 | 0.94 | 0.92 | 0.80 | 0.93 | 1.02 | 0.83 | 0.88 |
| median | para | $B^{sp}_{2020}/B_{MSY}$ | 1.05 | 1.12 | 1.04 | 1.06 | 1.12 | 1.01 | 0.99 | 0.72 | 1.15 | 1.07 |
| median | cap | $B^{sp}_{2020}/B_{MSY}$ | 2.41 | 1.11 | 2.64 | 1.82 | 1.90 | 2.13 | 2.38 | 2.11 | 1.92 | 2.03 |
| median | BS | AAV | 3.5 | 3.9 | 3.5 | 3.6 | 3.6 | 3.5 | 3.5 | 7.6 | 4.0 | 3.5 |
| low | BS | lowest TAC (2011-2030) | 105.6 | 93.9 | 109.0 | 99.7 | 102.6 | 109.1 | 106.3 | 31.4 | 113.0 | 96.3 |
| | BS | Prob decl >20% (2011-2013) | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 71.0 | 0.0 | 0.0 |
| | BS | Prob decl >20% (2012-2014) | 0.0 | 0.0 | 0.0 | 1.0 | 0.0 | 0.0 | 0.0 | 66.0 | 0.0 | 0.0 |
| median | BS | Pdecl>20% (2011-2028) | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.2 | 0.0 | 0.0 |
| high | BS | Pdecl>20% (2011-2028) | 0.0 | 0.1 | 0.0 | 0.1 | 0.0 | 0.0 | 0.0 | 0.3 | 0.1 | 0.0 |

| | | | RS1 | Rob16 | Rob17 | Rob18 | Rob19a | Rob19b | Rob19c | Rob20a | Rob20b | Rob20c |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| median | BS | avC: 2011-2020 | 138.2 | 142.7 | 155.2 | 145.1 | 145.2 | 145.6 | 133.5 | 138.6 | 137.4 | 138.7 |
| low | para | $B^{sp}_{low}/B^{sp}_{2010}$ | 0.83 | 1.00 | 0.80 | 0.79 | 0.83 | 0.78 | 0.87 | 0.83 | 0.83 | 0.79 |
| low | cap | $B^{sp}_{low}/B^{sp}_{2010}$ | 0.98 | 1.05 | 0.82 | 0.94 | 1.00 | 0.88 | 1.02 | 0.98 | 0.97 | 0.98 |
| median | para | $B^{sp}_{2020}/B_{MSY}$ | 1.05 | 0.85 | 1.06 | 1.33 | 1.03 | 0.97 | 1.27 | 1.05 | 1.06 | 0.96 |
| median | cap | $B^{sp}_{2020}/B_{MSY}$ | 2.41 | 3.76 | 1.90 | 2.12 | 1.99 | 1.84 | 2.52 | 2.42 | 2.38 | 2.41 |
| median | BS | AAV | 3.5 | 3.4 | 4.3 | 3.7 | 3.6 | 3.8 | 3.5 | 3.5 | 3.6 | 3.6 |
| low | BS | lowest TAC (2011-2030) | 105.6 | 117.2 | 119.3 | 113.3 | 118.9 | 115.8 | 90.8 | 106.4 | 103.9 | 105.5 |
| | BS | Prob decl >20% (2011-2013) | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 5.0 | 0.0 | 0.0 | 0.0 |
| | BS | Prob decl >20% (2012-2014) | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 2.0 | 0.0 | 1.0 | 0.0 |
| median | BS | Pdecl>20% (2011-2028) | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 |
| high | BS | Pdecl>20% (2011-2028) | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.1 | 0.0 | 0.0 | 0.0 |

| | | | RS1 | Rob21 | Rob22 | Rob23 | Rob24a | Rob24b | Rob25 | Rob26 | Rob27 | Rob28 |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| median | BS | avC: 2011-2020 | 138.2 | 141.4 | 152.6 | 136.6 | 138.0 | 138.3 | 115.2 | 153.5 | 140.2 | 146.1 |
| low | para | $B^{sp}_{low}/B^{sp}_{2010}$ | 0.83 | 0.78 | 0.62 | 0.86 | 0.84 | 0.82 | 0.53 | 0.74 | 0.84 | 0.87 |
| low | cap | $B^{sp}_{low}/B^{sp}_{2010}$ | 0.98 | 0.89 | 0.79 | 1.00 | 0.98 | 0.98 | 1.07 | 1.00 | 0.97 | 0.94 |
| median | para | $B^{sp}_{2020}/B_{MSY}$ | 1.05 | 1.06 | 0.83 | 1.10 | 1.05 | 1.05 | 0.58 | 1.23 | 1.14 | 1.14 |
| median | cap | $B^{sp}_{2020}/B_{MSY}$ | 2.41 | 1.60 | 1.15 | 1.92 | 2.35 | 2.48 | 2.11 | 2.47 | 2.55 | 1.85 |
| median | BS | AAV | 3.5 | 3.8 | 4.3 | 3.5 | 3.5 | 3.6 | 4.5 | 4.0 | 3.6 | 3.9 |
| low | BS | lowest TAC (2011-2030) | 105.6 | 101.5 | 114.8 | 103.1 | 105.3 | 105.8 | 69.4 | 122.1 | 110.0 | 117.9 |
| | BS | Prob decl >20% (2011-2013) | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 6.0 | 0.0 | 0.0 | 0.0 |
| | BS | Prob decl >20% (2012-2014) | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 8.0 | 0.0 | 0.0 | 0.0 |
| median | BS | Pdecl>20% (2011-2028) | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 |
| high | BS | Pdecl>20% (2011-2028) | 0.0 | 0.1 | 0.1 | 0.0 | 0.0 | 0.0 | 0.1 | 0.0 | 0.0 | 0.0 |

| | | | RS1 | Rob29 | Rob34a | Rob34b | Rob35 | Rob36a | Rob36b | Rob36c | Rob37 | Rob38 |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| median | BS | avC: 2011-2020 | 138.2 | 139.4 | 138.0 | 138.6 | 142.5 | 142.4 | 139.3 | 140.8 | 137.3 | 138.2 |
| low | para | $B^{sp}_{low}/B^{sp}_{2010}$ | 0.83 | 0.80 | 0.82 | 0.84 | 0.74 | 0.93 | 0.85 | 0.88 | 0.52 | 0.83 |
| low | cap | $B^{sp}_{low}/B^{sp}_{2010}$ | 0.98 | 1.04 | 1.00 | 0.96 | 0.95 | 1.06 | 1.01 | 1.03 | 0.49 | 0.98 |
| median | para | $B^{sp}_{2020}/B_{MSY}$ | 1.05 | 0.98 | 1.02 | 1.09 | 0.97 | 1.25 | 1.11 | 1.18 | 1.31 | 1.05 |
| median | cap | $B^{sp}_{2020}/B_{MSY}$ | 2.41 | 2.53 | 2.46 | 2.34 | 2.37 | 2.75 | 2.60 | 2.67 | 3.12 | 2.41 |
| median | BS | AAV | 3.5 | 3.6 | 3.6 | 3.5 | 3.6 | 3.6 | 3.6 | 3.6 | 6.0 | 3.5 |
| low | BS | lowest TAC (2011-2030) | 105.6 | 106.0 | 105.4 | 105.9 | 115.0 | 113.1 | 107.2 | 109.8 | 45.2 | 105.6 |
| | BS | Prob decl >20% (2011-2013) | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 |
| | BS | Prob decl >20% (2012-2014) | 0.0 | 1.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 |
| median | BS | Pdecl>20% (2011-2028) | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.1 | 0.0 |
| high | BS | Pdecl>20% (2011-2028) | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.2 | 0.0 |

Table 10.7b: Projections results (either median, lower or upper 2.5%ile) for a series of performance statistics for CMPe137 under the full set of robustness tests based on RS11 (*M. capensis* in need of rebuilding). The "low para $B^{sp}_{low}/B^{sp}_{2010}$" cells are shaded if values are less than 0.7 (the 2007 level); the "lowest TAC (2011-2030)" cells are shaded if less than 95 (thousand tons).

| | | | RS11 | Rob5 | Rob13 | Rob25 | Rob37 |
|---|---|---|---|---|---|---|---|
| median | BS | avC: 2011-2020 | 130.6 | 132.0 | 90.0 | 128.9 | 128.9 |
| low | para | $B^{sp}_{low}/B^{sp}_{2010}$ | 0.93 | 1.00 | 0.38 | 0.78 | 0.78 |
| low | cap | $B^{sp}_{low}/B^{sp}_{2010}$ | 0.84 | 0.75 | 0.92 | 0.69 | 0.69 |
| median | para | $B^{sp}_{2020}/B_{MSY}$ | 0.89 | 0.78 | 0.99 | 1.10 | 1.10 |
| median | cap | $B^{sp}_{2020}/B_{MSY}$ | 0.58 | 0.52 | 2.85 | 0.74 | 0.74 |
| median | BS | AAV | 3.5 | 3.4 | 8.2 | 4.4 | 4.4 |
| low | BS | lowest TAC (2011-2030) | 87.2 | 96.0 | 36.5 | 61.5 | 61.5 |

Table 10.8: GLM-standardised CPUE series (Glazer 2010) and survey biomass estimates (Fairweather and Sithole 2010) used as input in the 2011 TAC computation. The biomass estimates shaded are for surveys that have been conducted with the new gear on the *F.R.S. Africana*.

| | *M. paradoxus* | | | | *M. capensis* | | | |
|---|---|---|---|---|---|---|---|---|
| | West Coast CPUE | South Coast CPUE | West coast summer survey | South Coast autumn survey | West Coast CPUE | South Coast CPUE | West coast summer survey | South Coast autumn survey |
| 2004 | 2.0610 | 1.3252 | | | 0.8383 | 1.9092 | | |
| 2005 | 2.2117 | 1.3150 | 286.42 | 26.61 | 0.4944 | 1.5028 | 70.98 | 76.93 |
| 2006 | 2.3641 | 1.3678 | 315.31 | 34.80 | 0.5640 | 1.1991 | 88.42 | 130.90 |
| 2007 | 2.7567 | 1.4412 | 392.81 | 129.65 | 0.5972 | 1.0488 | 82.27 | 70.94 |
| 2008 | 3.4236 | 1.3913 | 246.54 | 39.51 | 0.5028 | 1.6515 | 50.88 | 108.20 |
| 2009 | 3.6006 | 1.6309 | 330.24 | 102.83 | 1.0335 | 3.0417 | 175.29 | 124.00 |
| 2010 | | | 592.57 | 169.56 | | | 164.66 | 184.96 |

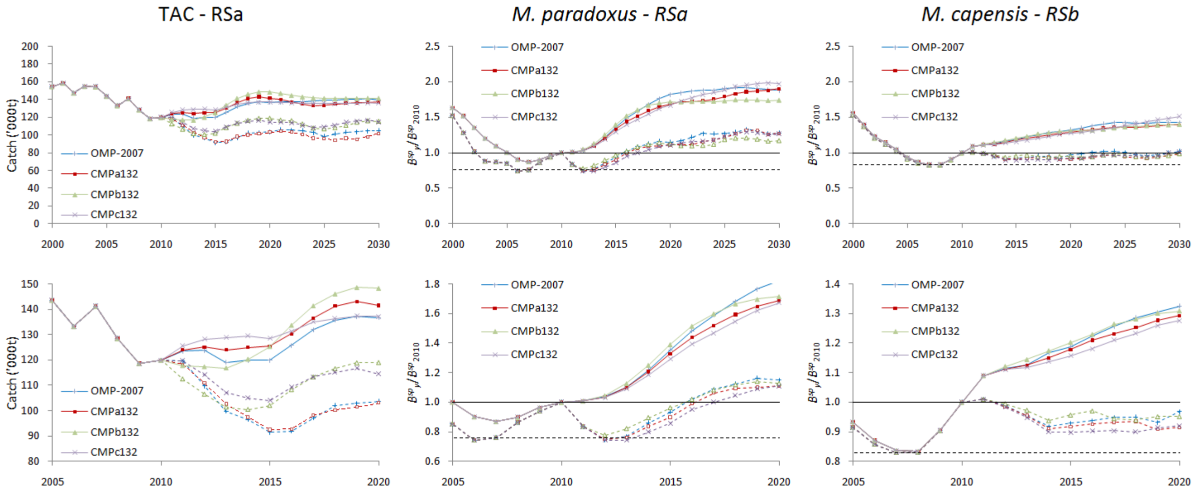


Figure 10.1a: Median (full lines) and lower 2.5%iles (dashed lines) TAC (RSa) and spawning biomass (in terms of 2010 level) for *M. paradoxus* (RSa) and *M. capensis* (RSb) for OMP-2007, CMPa132, CMPb132 and CMPc132. The horizontal dashed line shows the 2007 level. Here and in plots below, the bottom row repeats the top row, but with different scales for improved discrimination.

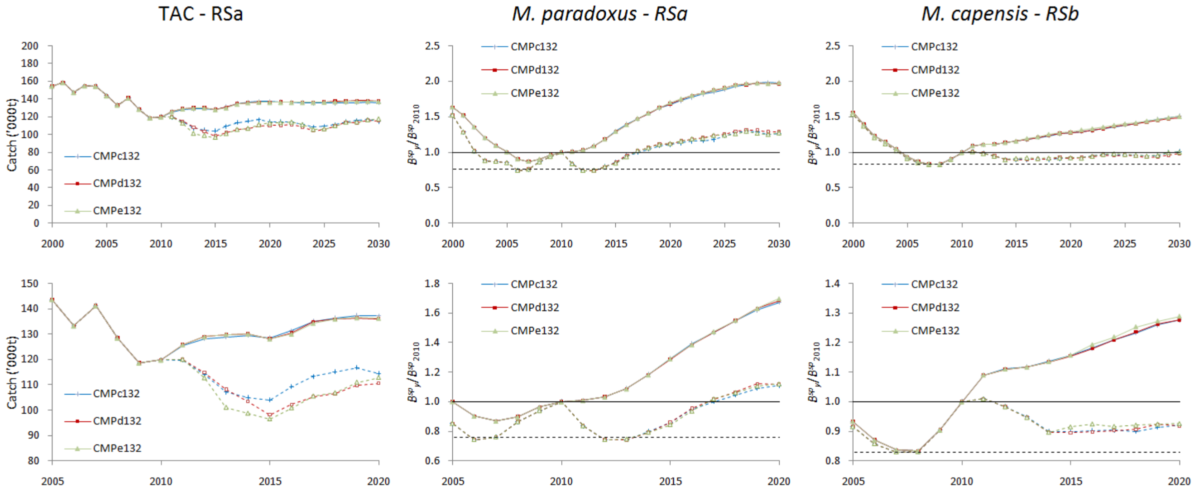


Figure 10.1b: Median (full lines) and lower 2.5%iles (dashed lines) TAC (RSa) and spawning biomass (in terms of 2010 level) for *M. paradoxus* (RSa) and *M. capensis* (RSb) for CMPc132, CMPd132 and CMPe132. The horizontal dashed line shows the 2007 level.

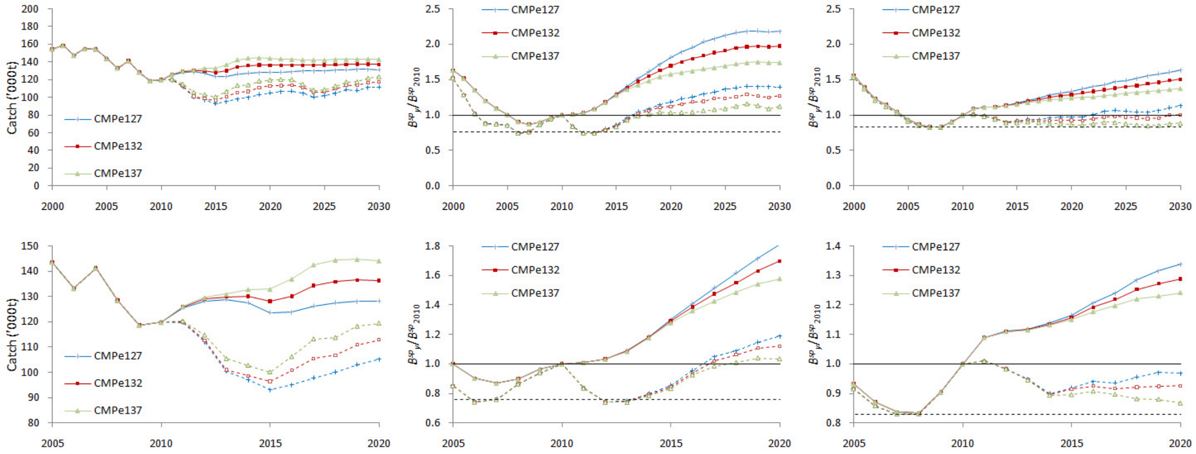


Figure 10.1c: Median (full lines) and lower 2.5%iles (dashed lines) TAC (RSa) and spawning biomass (in terms of 2010 level) for *M. paradoxus* (RSa) and *M. capensis* (RSb) for CMPe127, CMPe132 and CMPe137. The horizontal dashed line shows the 2007 level.

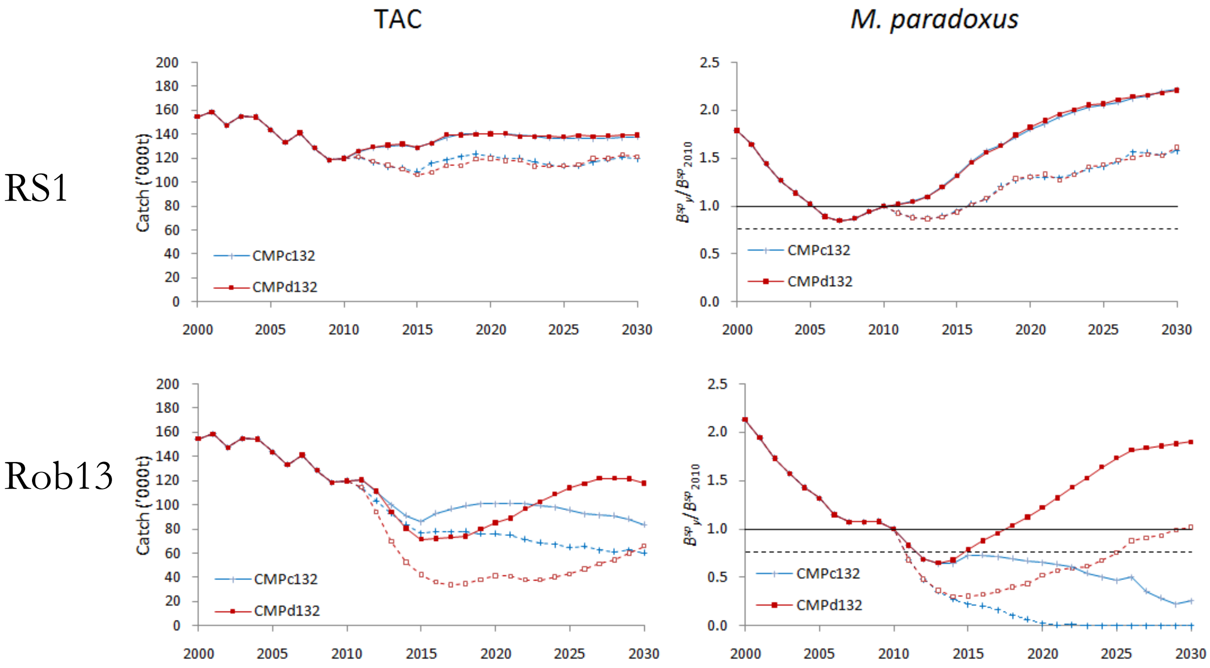


Figure 10.2: Median (full lines) and lower 2.5%iles (dashed lines) TAC and spawning biomass (in terms of 2010 level) for *M. paradoxus* for CMPc132 (no extra penalty) and CMPd132 (with extra penalty) under RS1 and the most severe robustness test, also based on RS1, Rob13 (decrease in *K* in the past).

Figure 10.3a: 95, 75, 50% PI and median for a series of performance statistics for **CMPd127**.

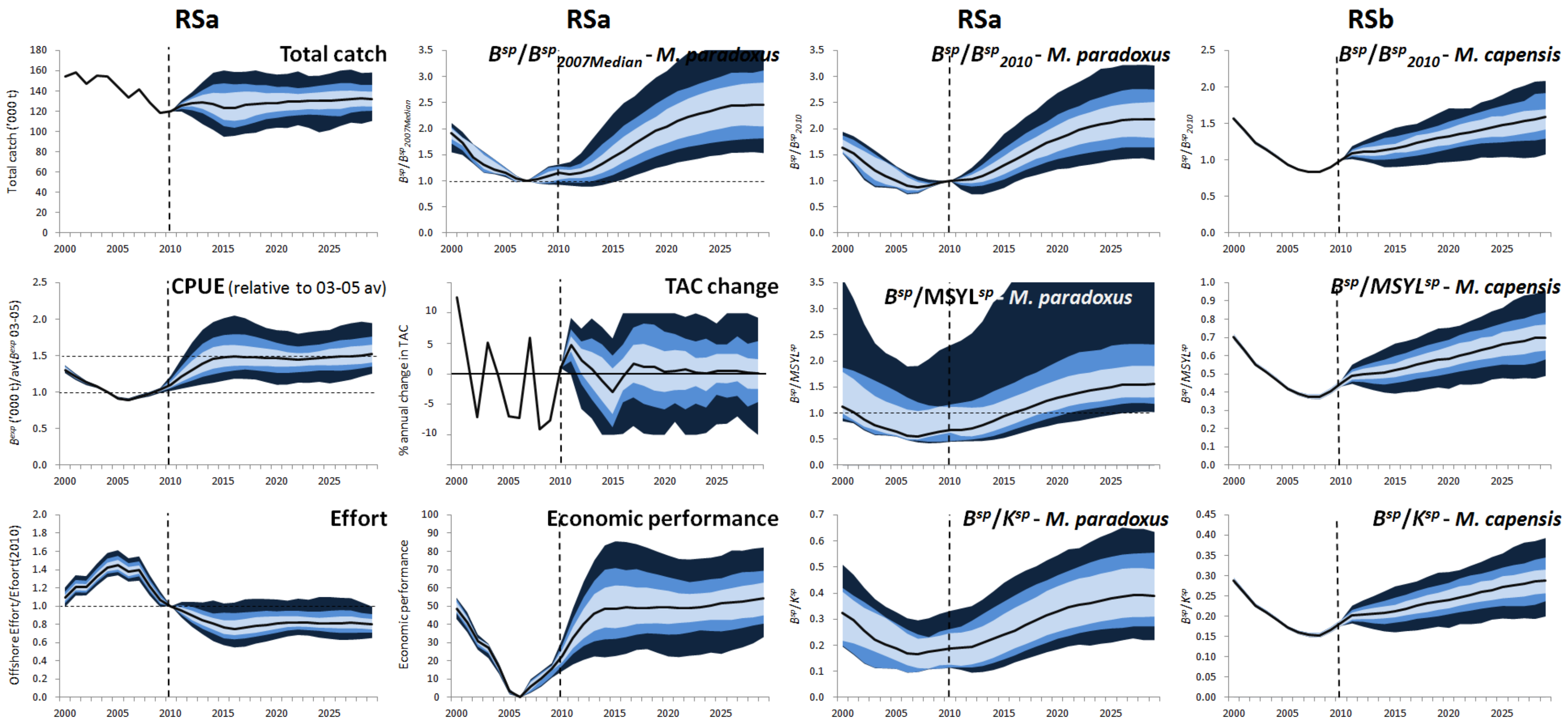


Figure 10.3b: 95, 75, 50% PI and median for a series of performance statistics for **CMPd132**.

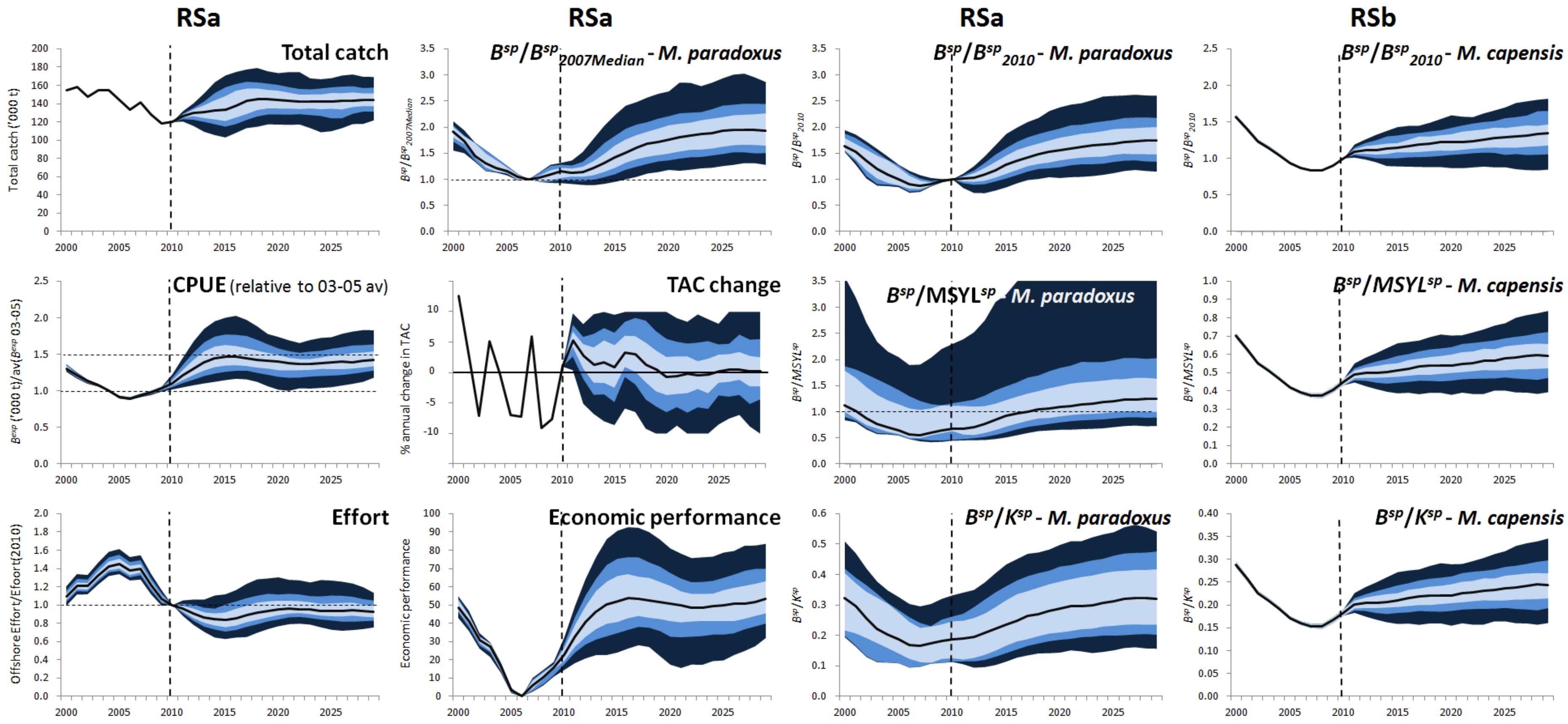


Figure 10.3c: 95, 75, 50% PI envelopes and medians for a series of performance statistics for **CMPd137**.

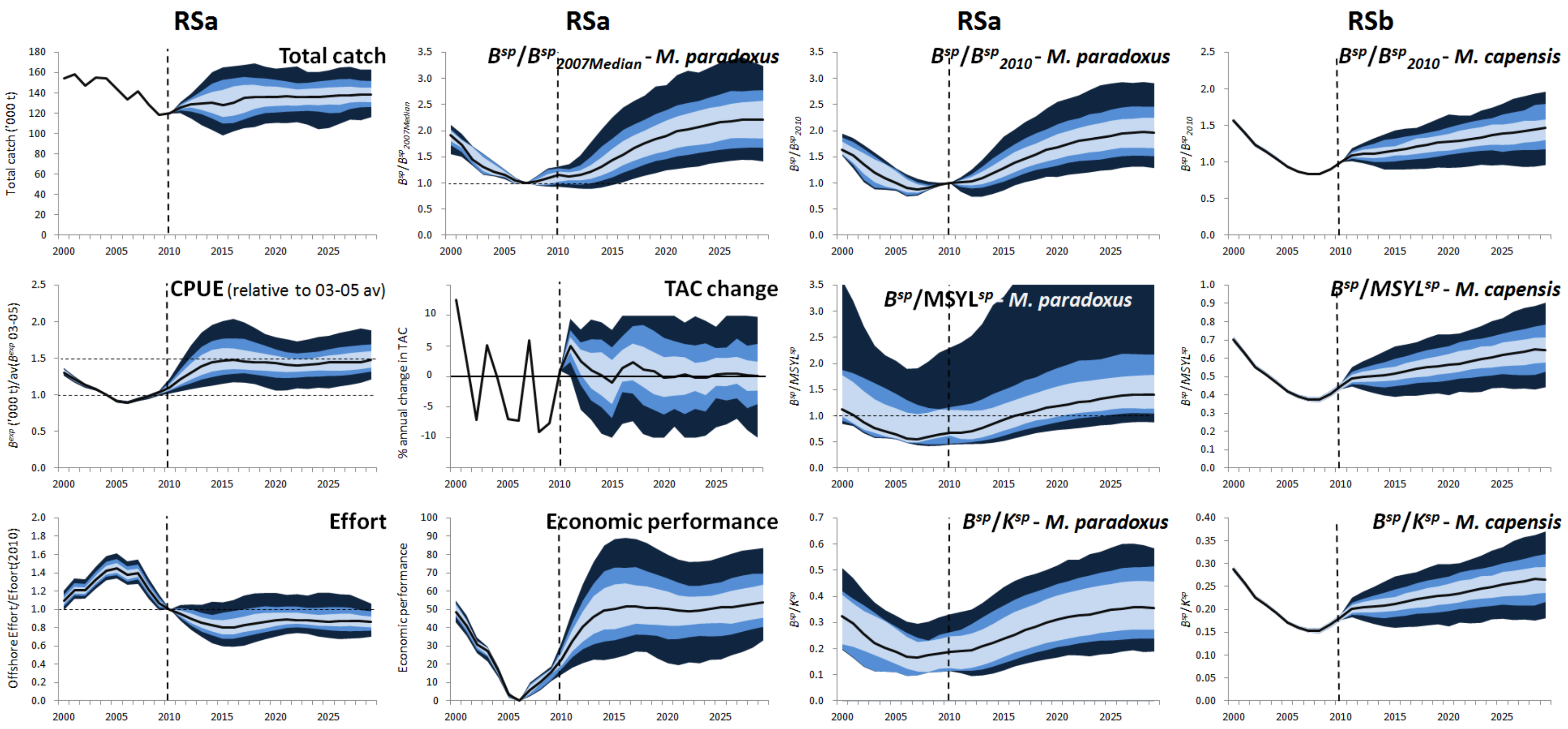


Figure 10.3d: 95, 75, 50% PI envelopes and medians for a series of performance statistics for **CMPe127**.

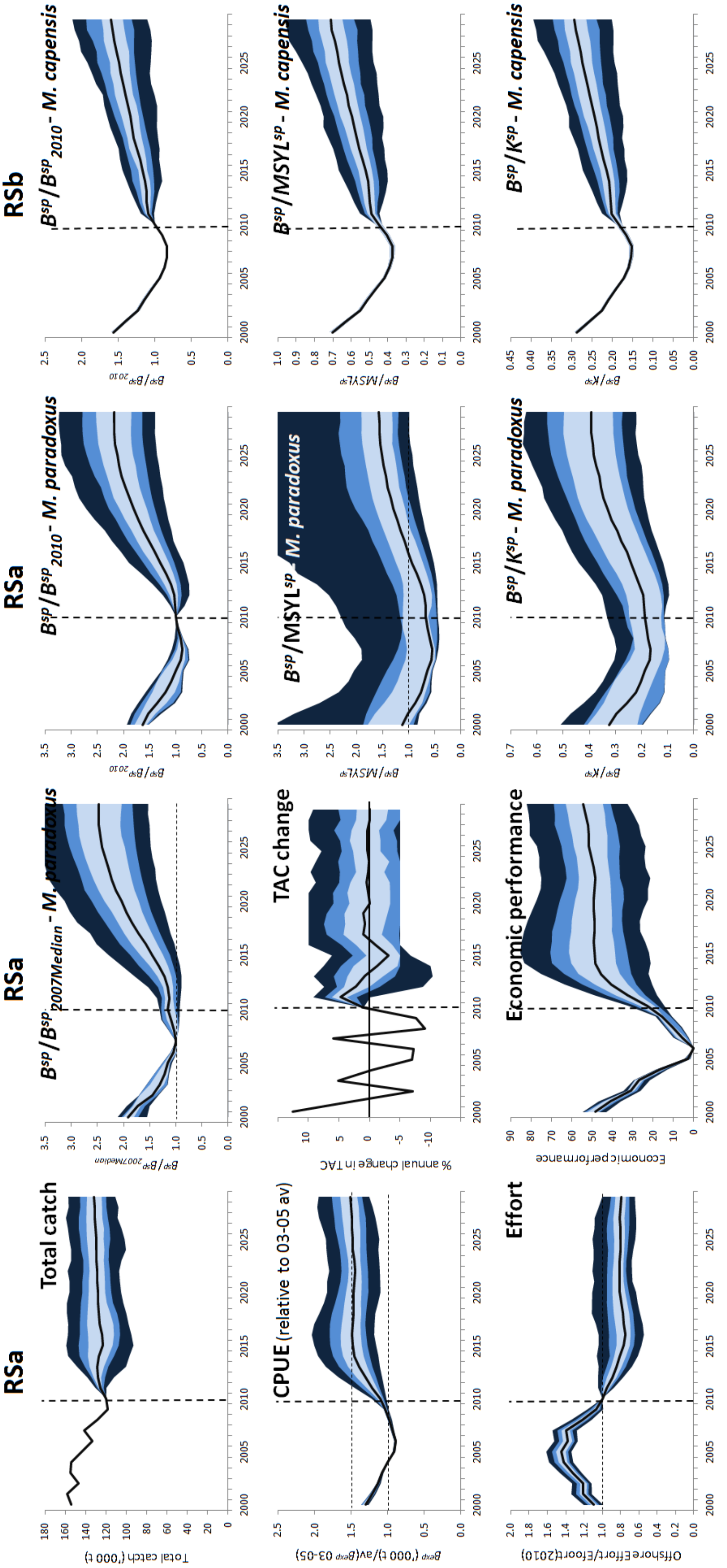


Figure 10.3e: 95, 75, 50% PI envelopes and medians for a series of performance statistics for **CMPe132**.

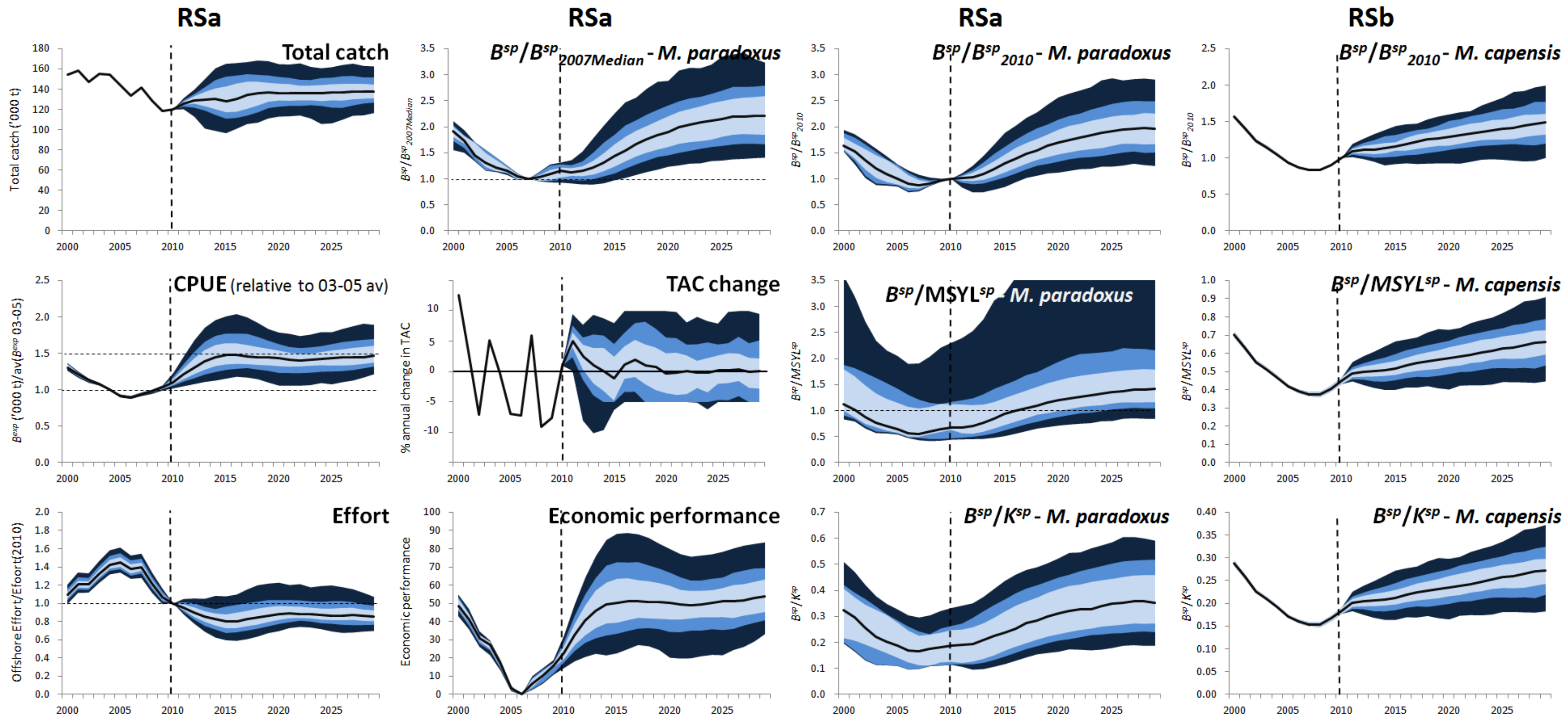
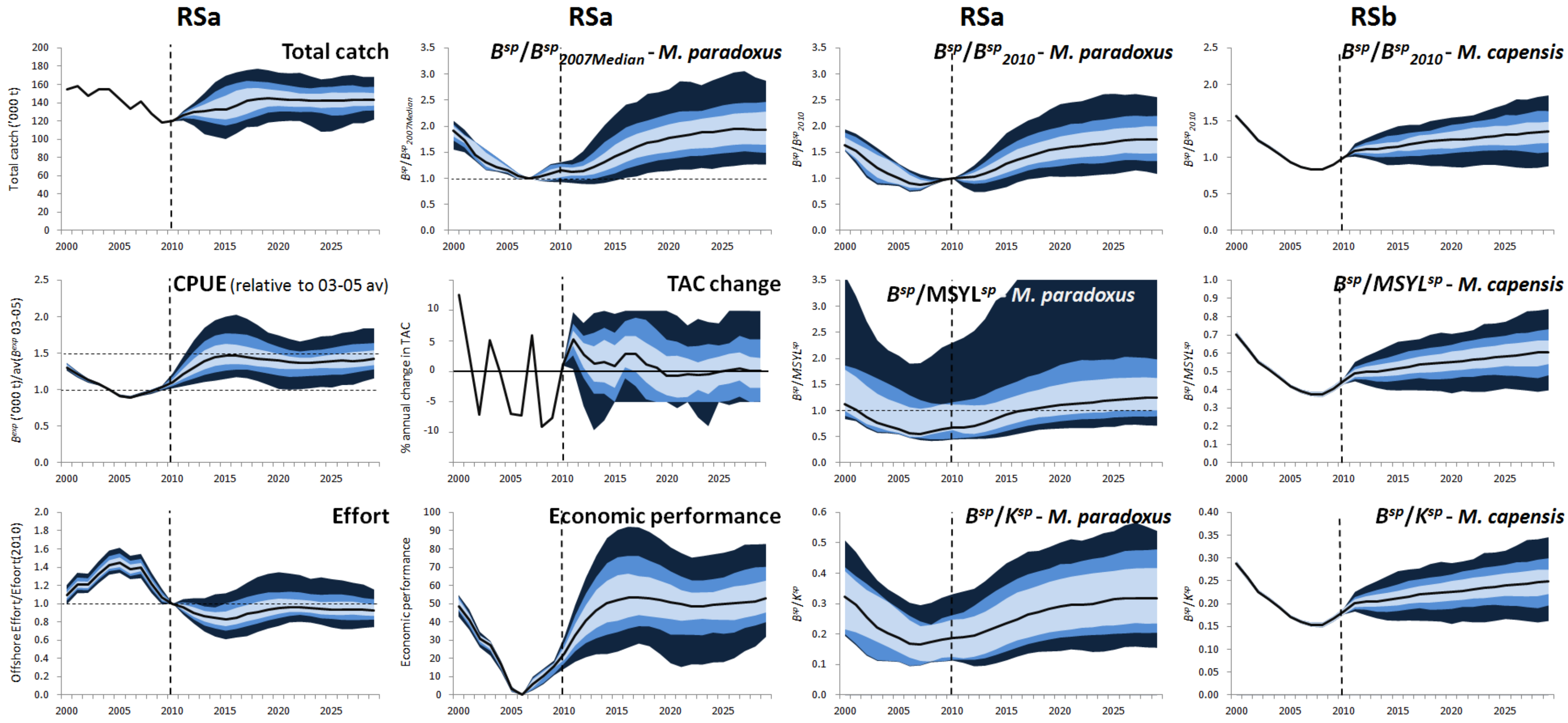


Figure 10.3f: 95, 75, 50% PI envelopes and medians for a series of performance statistics for **CMPe137**.



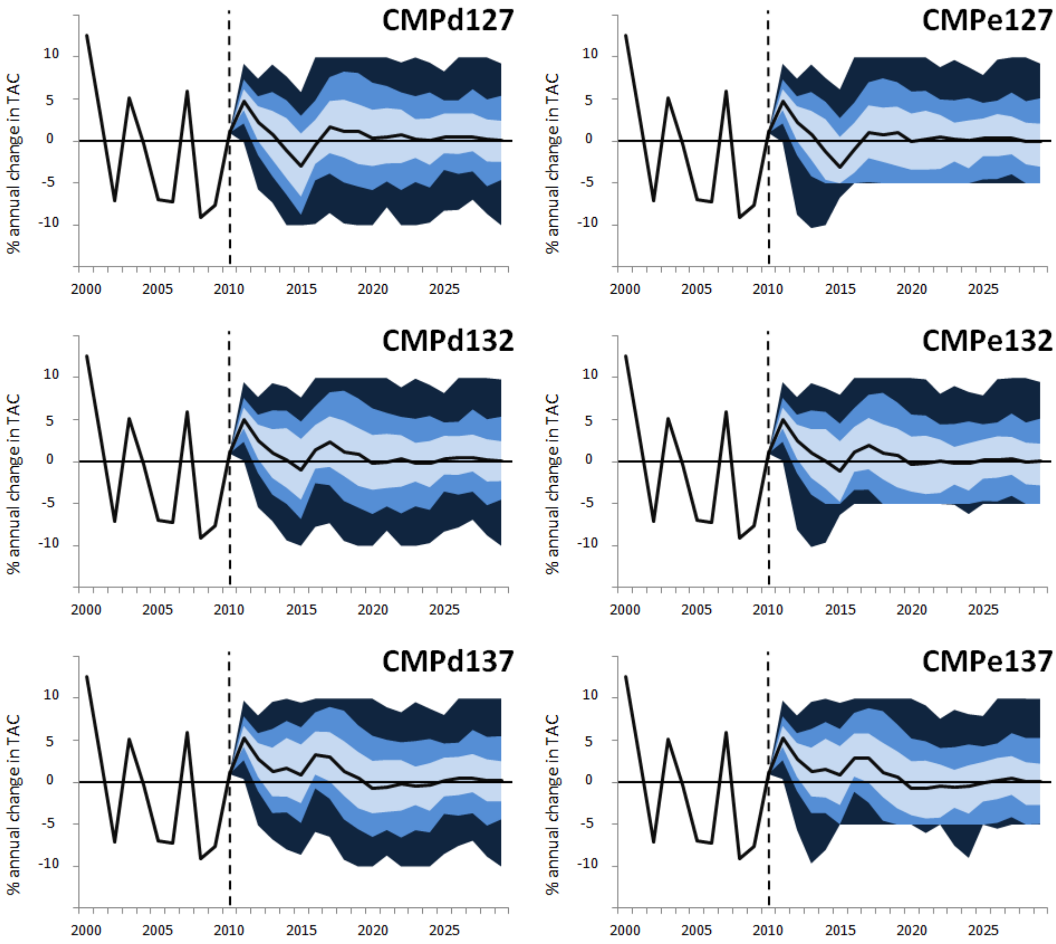


Figure 10.3g: 95, 75, 50% PI envelopes and medians for the percentage annual change in TAC for each of the six final CMPs.

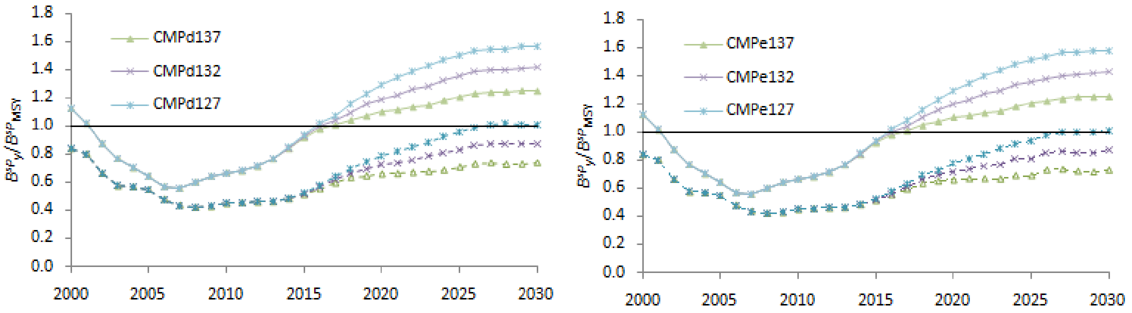


Figure 10.4: Median (full lines) and lower 2.5%iles (dashed lines) for spawning biomass (in terms of $B^{sp}_{MSY}$) for *M. paradoxus* for the final set of CMPs based on RSa.

Figure 10.5: Performance statistics (medians) under the final set of CMPs for the RS. The bars show the 95% PIs.

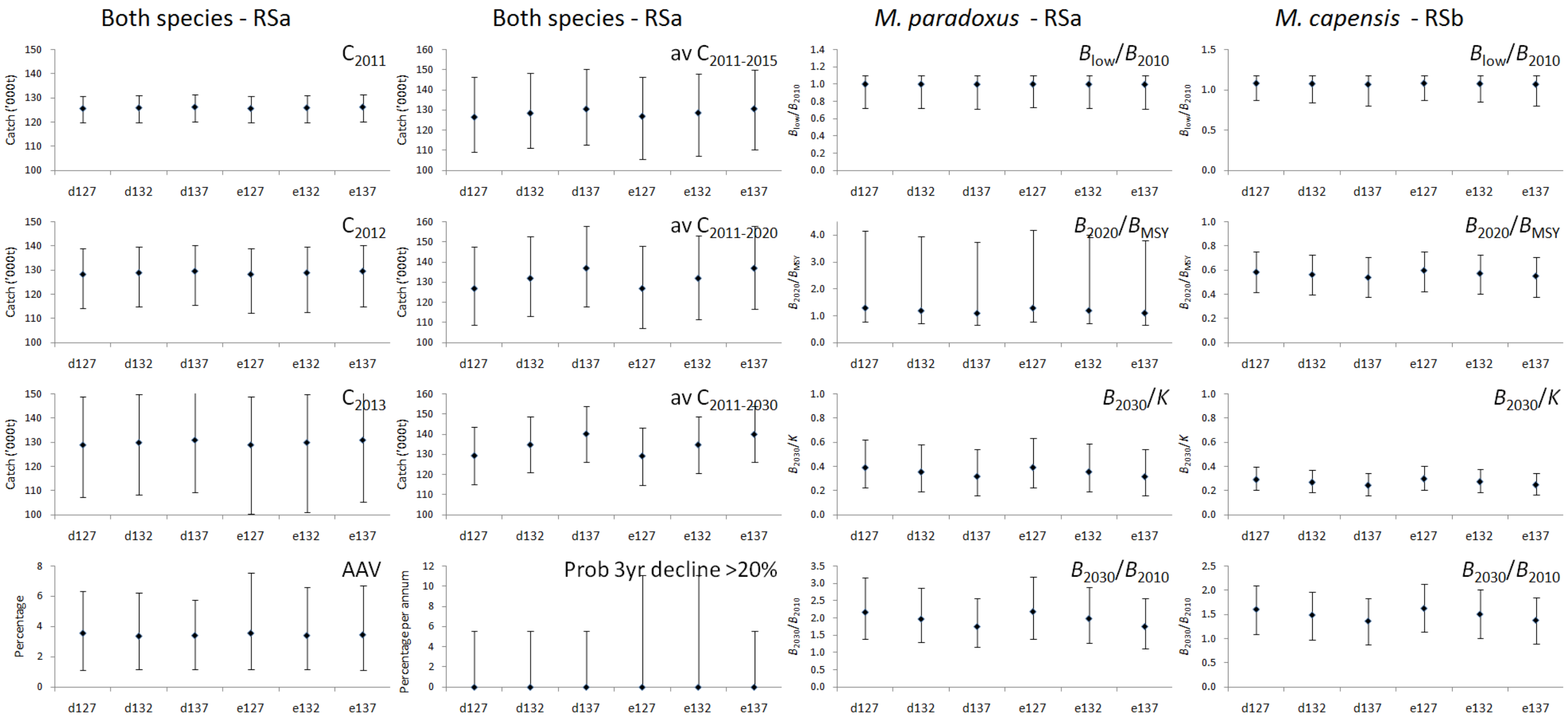


Figure 10.6: Performance statistics (medians) under CMPe137 for the full set of robustness tests. The bars show the 95% PIs.

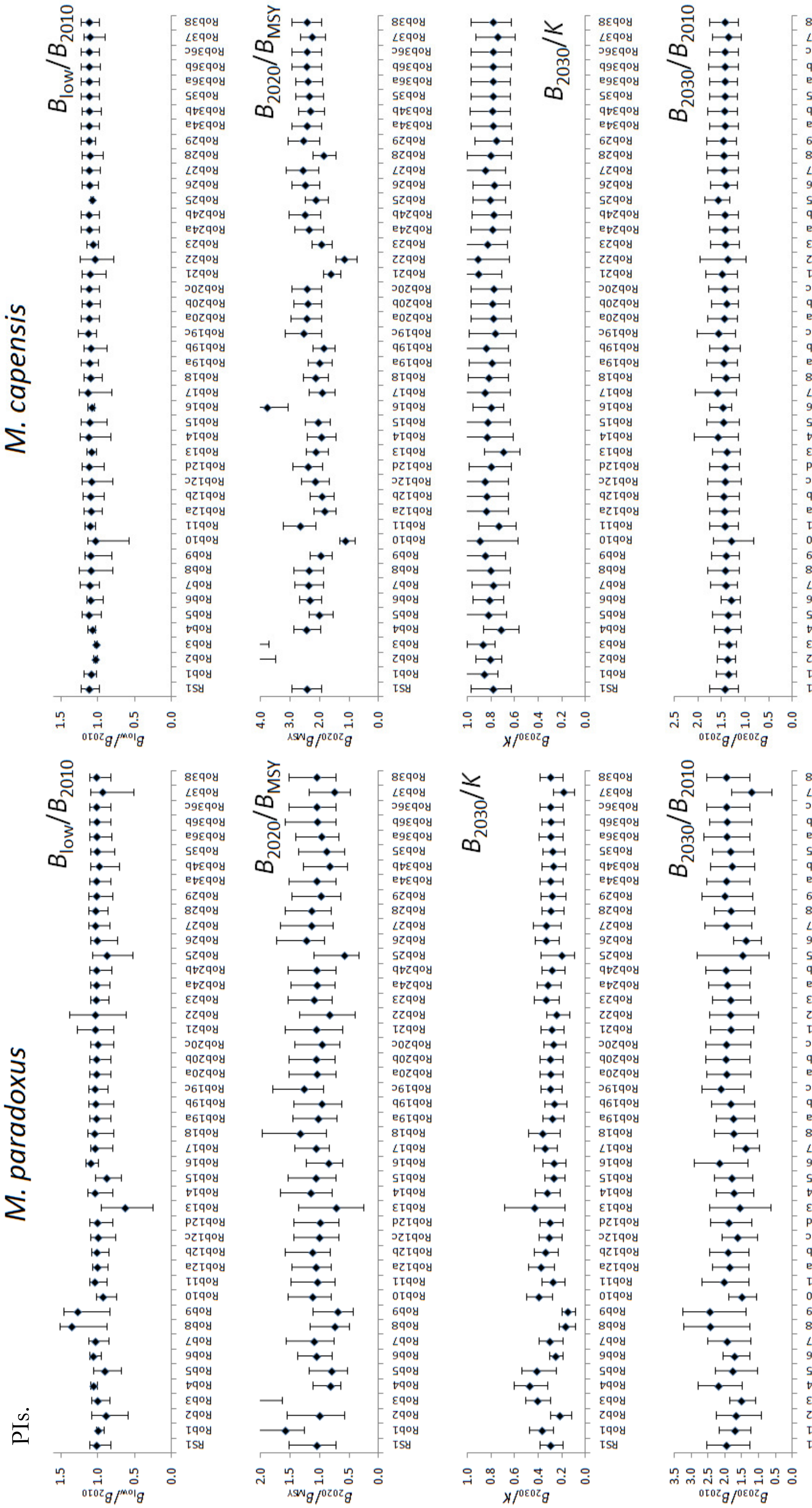
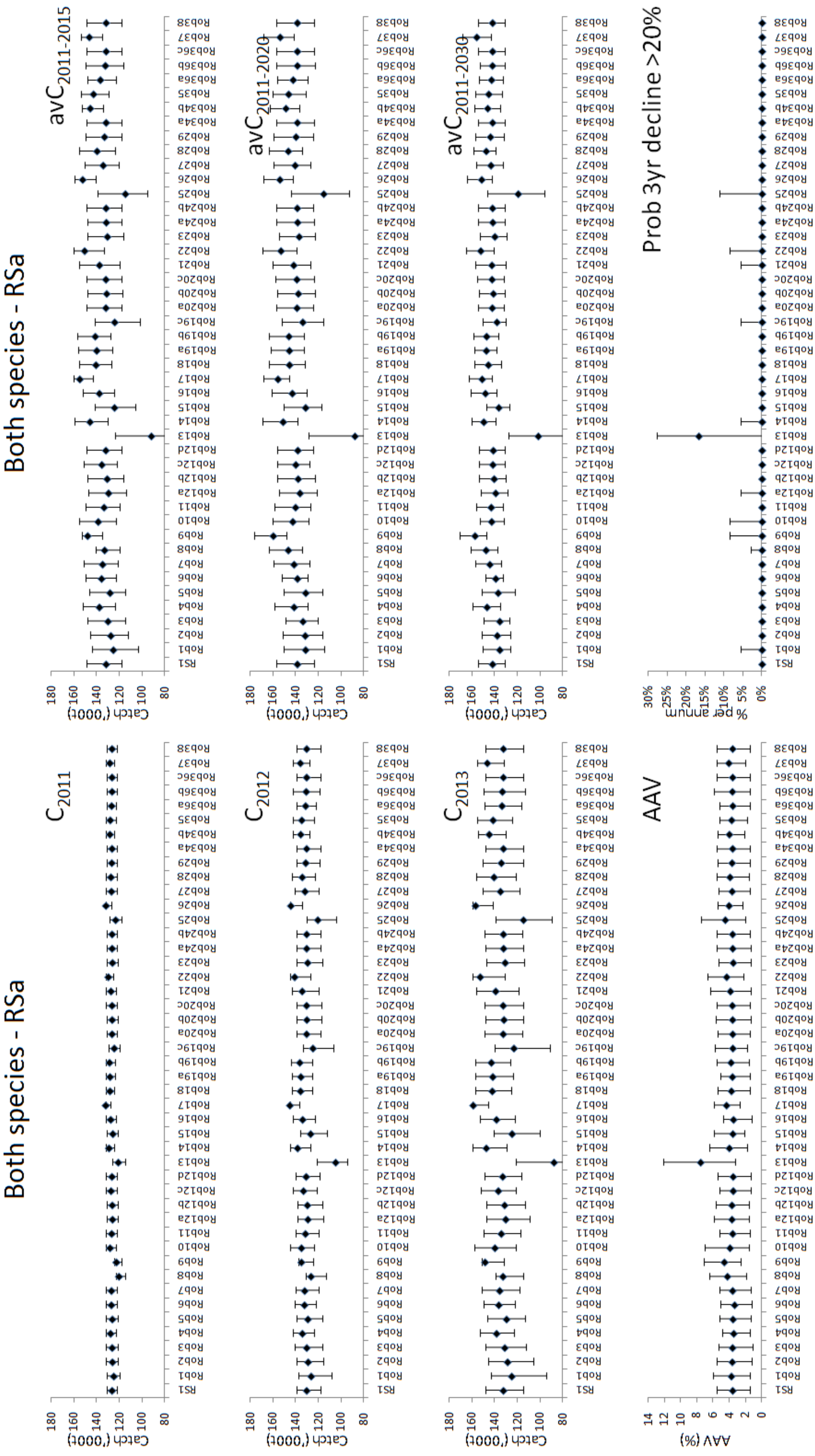


Figure 10.6: continued



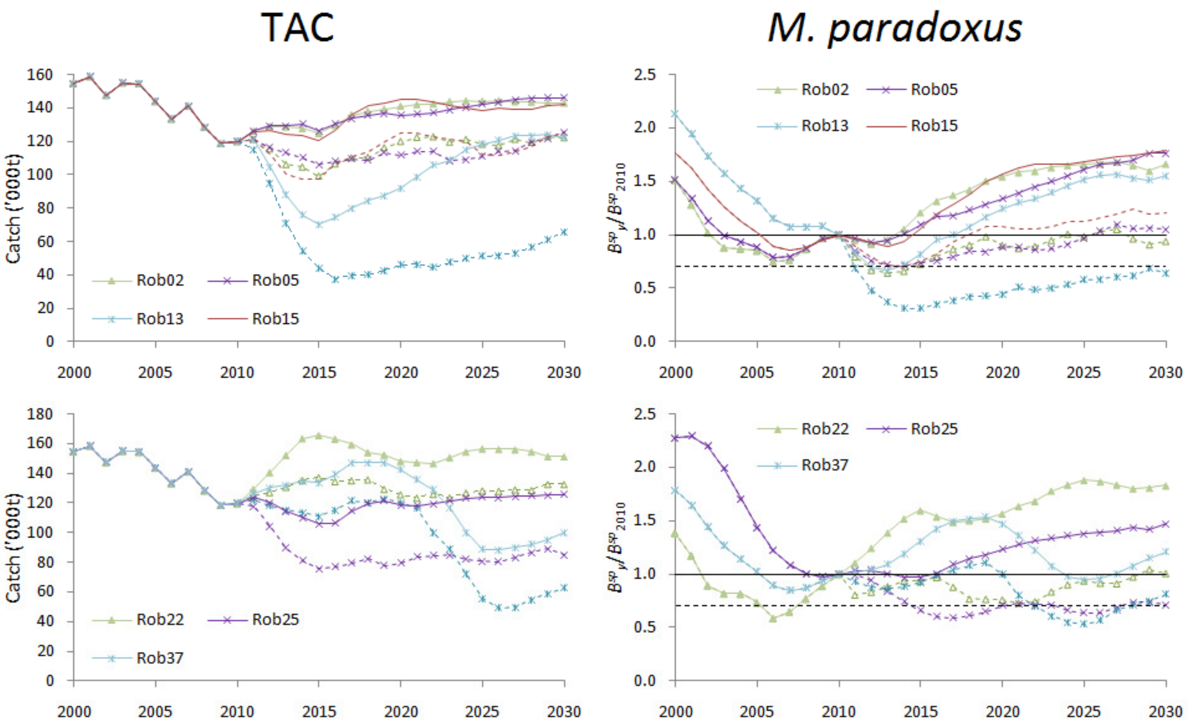


Figure 10.7: Median (full lines) and lower 2.5%iles (dashed lines) TAC and spawning biomass (in terms of 2010 level) for *M. paradoxus* for the more difficult robustness tests based on the RC, under CMPe137. The horizontal dashed line shows the 2007 level. The robustness tests are:

Rob02: BH est., shift center in 1950, paradoxus: $M_{2-}$=0.9, $M_{5+}$=0.5, capensis: $M_{2-}$=0.6, $M_{5+}$=0.5;

Rob05: True Ricker, shift center in 1950, both species: $M_{2-}$=0.9, $M_{5+}$=0.5;

Rob13: Decrease in $K$ in the past;

Rob15: No shrinking of recent recruitment towards the stock-recruitment relationship predicted;

Rob22: Ageing of both species to be halved;

Rob25: Alternative maturity-at-length with fixed lower $h$ value;

Rob37: Decrease in $K$ in the future.

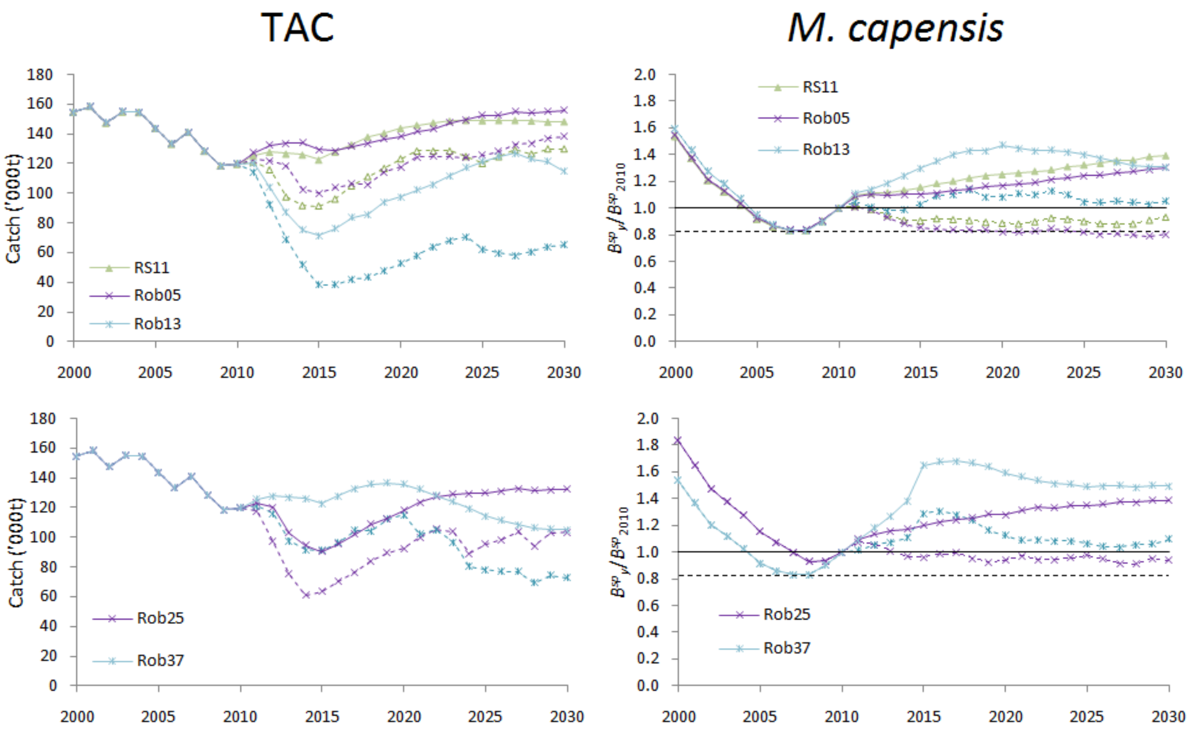


Figure 10.8: Median (full lines) and lower 2.5%iles (dashed lines) TAC and spawning biomass (in terms of 2010 level) for *M. paradoxus* for the robustness tests based on RS11 (*M. capensis* in need of rebuilding), under CMPe137. The horizontal dashed line shows the 2007 level. The robustness tests are:

Rob05: True Ricker, shift center in 1950, both species: $M_{2-}$=0.9, $M_{5+}$=0.5;

Rob13: Decrease in $K$ in the past;

Rob25: Alternative maturity-at-length with fixed lower $h$ value;

Rob37: Decrease in $K$ in the future.

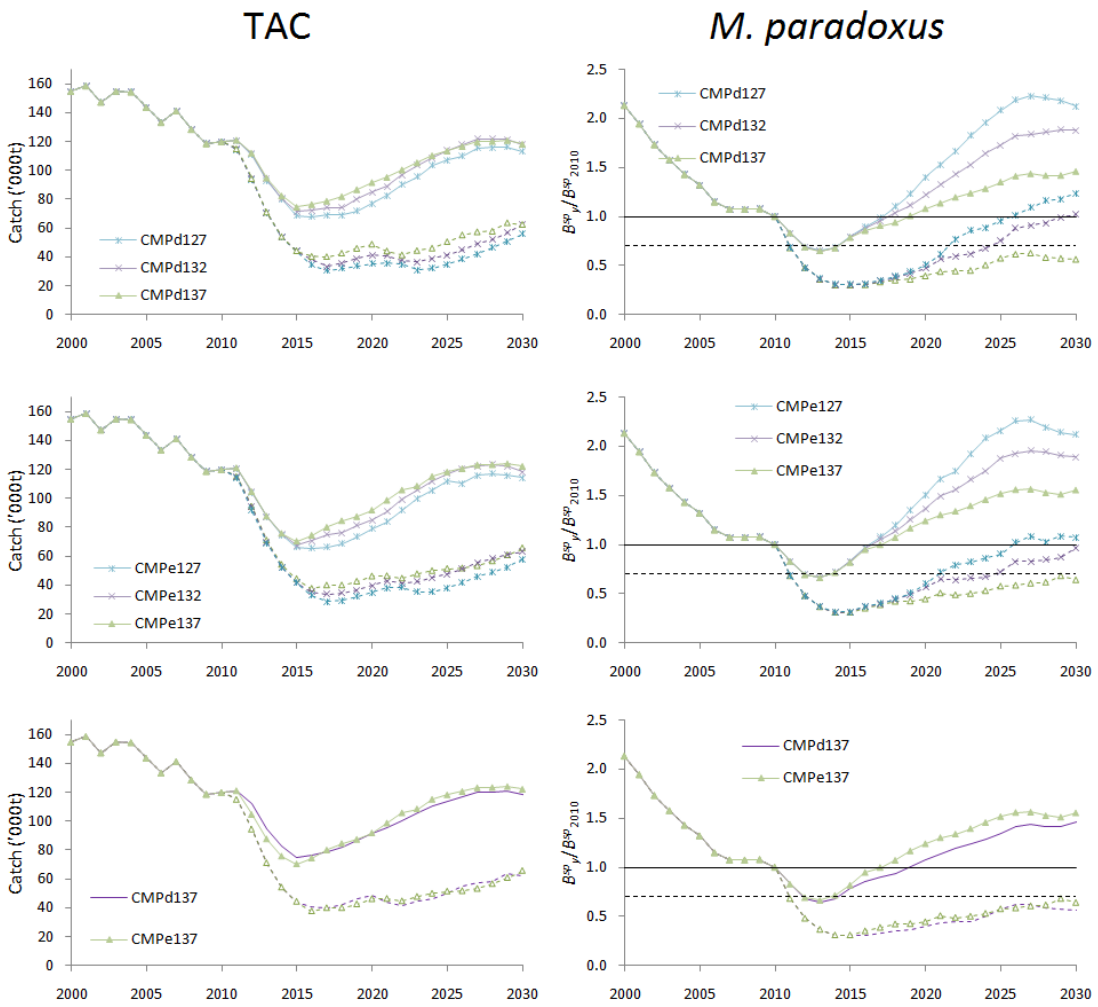


Figure 10.9: Median (full lines) and lower 2.5%iles (dashed lines) TAC and spawning biomass (in terms of 2010 level) for *M. paradoxus* for the final set of CMPs based on Rob13 (decrease in *K* in the past). The horizontal dashed line shows the 2007 level.

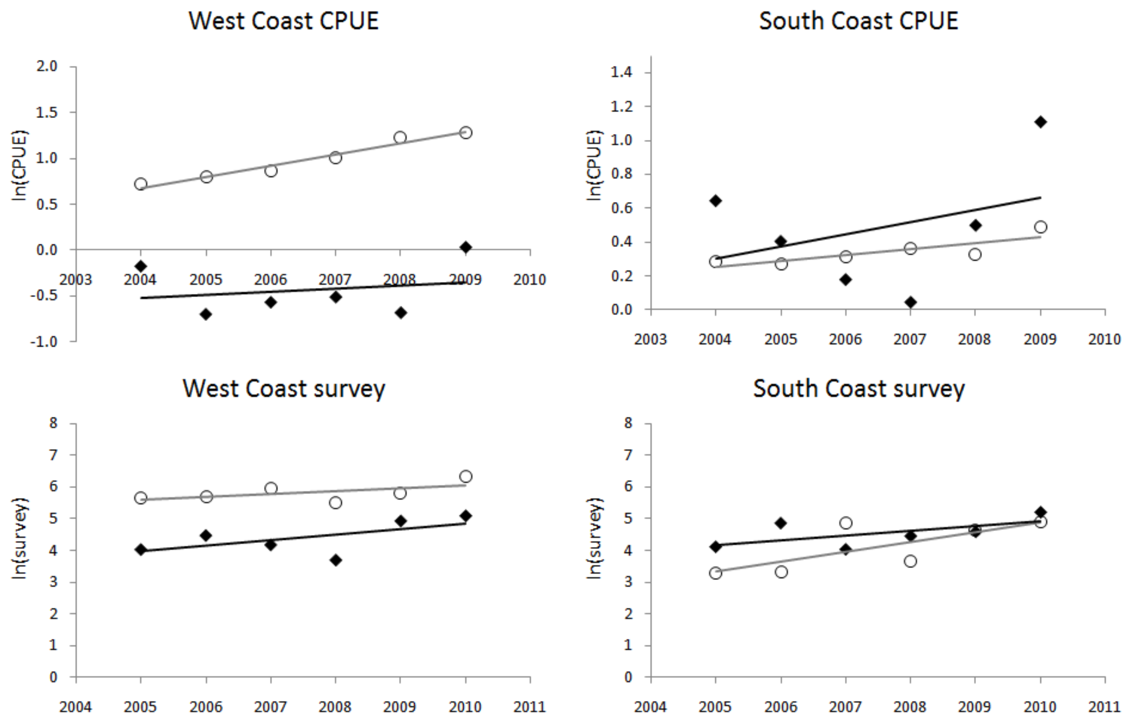


Figure 10.10: Recent trends in the GLM-standardised CPUE and survey biomass indices for *M. paradoxus* (open circles) and *M. capensis* (filled diamonds) which are used in the TAC computation. The survey biomass estimates shown include the calibration factors specified in the OMP for the years in which the new gear was used on the *F.R.S. Africana*.

# APPENDIX 10.I

# Candidate Management Procedures Testing Methodology

## 10.I.1 Projection Methodology

Projections into the future under a specific Candidate Management Procedure (CMP) are evaluated using the following steps for the Operating Model (OM) under consideration.

**Step 1: Begin-year numbers at age**

The components of the numbers-at-age vector for each gender and species at the start of 2010 ($N^g_{2010,a}$: $a$ = 1,…, $m$ – here and below the species superscript has been omitted for ease of reading) are obtained from the MLE of an assessment of the resource, assuming a total catch in 2009 equal to the TAC set for that year and split between species, coast and fleet using the 2008 catch ratio.

Error is included for ages 0 to 3 because these are poorly estimated in the assessment given limited information on these year-classes, i.e.: $N^g_{2010,a} \rightarrow N^g_{2010,a}e^{\varepsilon_a}$

$$\varepsilon_a \text{ from } N\left(0,(\sigma_R)^2\right) \qquad \text{(App.10.I.1)}$$

where $\sigma_R$ is the standard deviation of the stock-recruitment residuals estimated by the OM for the years 1985 to 2005 (the last year before shrinking of SR residuals). Note that the residuals each year are assumed to be gender-independent. Equation App.10.I.1 is approximate in that it omits to adjust for past catches from the year-class concerned, but these are so small that the differential effect is negligible.

**Step 2: Catch**

These numbers-at-age are projected one year forward at a time given a catch for the year concerned. $C_y$ is as specified by the CMP.

This requires specification of how the catch is disaggregated by species, fleet, gender and age to obtain $C^g_{fya}$, and of how future recruitments are generated.

**Step 3: Catch-at-age by species, gender and fleet**

*Catch by species:*

Although the annual catch (TAC) generated by the CMP can be species-disaggregated, the TAC recommended by the MP will be an overall figure for the two species combined given the difficulties that would be encountered in trying to set species-specific hake TACs. To disaggregate the total catch by species, previous practice when projecting forward was to assume for each fleet that the ratio of the fishing mortality ($F$) for the two species ($F_{para}/F_{cap}$) remains the same, i.e. that the current pattern of fishing remains approximately unchanged over the projection period — although some robustness tests explored sensitivity to this). Figure App.10.I.1 shows plots of estimates of this ratio for the three fleets concerned, together with averages over recent periods, for the central OM within the Reference Set (the OM RS1). The averages over the last five years (2005–2009) might be used for this purpose; however given that there is variability from year to year evident in these plots, instead in each future year the ratio is drawn from a Normal distribution with mean and variance as estimated from the values over the last five years, except that these distributions are truncated at +2 and -2 standard deviations to avoid generation of outlying values.

*Catch by gender:*

The fishing mortality on males and females is assumed to be equal for each species and fleet, as assumed in the assessment, except for the South Coast offshore fishery for which the female downscaling factor estimated in the OM is used in the projection.

*Catch by fleet:*

The total TAC recommended by the CMP is divided in fixed proportions among the various fleets, with the following values used for the sector allocations as in the last rights re-allocation process for the fishery: offshore trawl — 84%, inshore trawl — 6%, longline — 7% and handline — 3%. The offshore trawl and longline fleet catches are further split between the West and South Coasts using the average proportion over the last five years data (2004-2008) (see Figure App.10.I:2). This should differ little from what happens in practice as the stocks each cover both coasts.

*Catch by age:*

$C^g_{fya}$ is obtained by assuming that $S^g_{fyl}$, $P^g_{a+1/2,l}$ and $\tilde{w}^g_{a+1/2}$ stay constant in the future as estimated in the OM, and therefore that:

$$S^g_{fya} = \sum_l S^g_{fyl} P^g_{a+1/2,l} \qquad \text{(App.10.I.2)}$$

the commercial selectivity functions, also stay constant in the projections.

The matrix $P$ is calculated under the assumption that length-at-age is log-normally distributed about a mean given by the von Bertalanffy equation, i.e.:

$$l_a \sim N\left[\ln(l_\infty\left(1-e^{-\kappa(a-t_0)}\right));\left(\frac{\theta_a}{l_\infty\left(1-e^{-\kappa(a-t_0)}\right)}\right)^2\right] \qquad \text{(App.10.I.3)}$$

where $\theta_a$, $l_\infty$, $t_0$ and $\kappa$ are as estimated in the OM for each species and gender.

From this it follows that:

$$C_{fy} = \sum_g \sum_{a=0}^{m} \tilde{w}^g_{fya+1/2}\, C^g_{fya} = \sum_g \sum_{a=0}^{m} \tilde{w}^g_{fya+1/2}\, N^g_{ya} e^{-M^g_a/2} F_{fy} S^g_{fya} \qquad \text{(App.10.I.4)}$$

$\tilde{w}^g_{fy,a+1/2}$ is the selectivity-weighted mid-year weight-at-age *a* of gender *g* for fleet *f* and year *y* (see equation App.8.11.9);

$$F_{fy}^{cap} = \frac{C_{fy}^{tot}}{\left[ F_{ratio} \sum_{g} \sum_{a=0}^{m} \tilde{w}_{fya+1/2}^{para,g} \ N_{ya}^{para,g} e^{-M_a^{para,g}/2} S_{fya}^{para,g} + \sum_{g} \sum_{a=0}^{m} \tilde{w}_{fya+1/2}^{cap,g} \ N_{ya}^{cap,g} e^{-M_a^{cap,g}/2} S_{fya}^{cap,g} \right]} \qquad \text{(App.10.I.5)}$$

$$F_{fy}^{para} = F_{fy}^{cap} F_{ratio}$$

and hence that:

$$C_{fya}^{g} = N_{ya}^{g} e^{-M_a^g/2} F_{fy} S_{fya}^{g} \qquad \text{(App.10.I.6)}$$

The numbers-at-age can then be computed for the beginning of the following year ($y$+1):

$$N_{y+1,0}^{g} = R_{y+1}^{g} \qquad \text{(App.10.I.7)}$$

$$N_{y+1,a+1}^{g} = \left( N_{ya}^{g} e^{-M_a^g/2} - \sum_{f} C_{fya}^{g} \right) e^{-M_a^g/2} \qquad \text{for } 0 \le a \le m-2 \qquad \text{(App.10.I.8)}$$

$$N_{y+1,m}^{g} = \left( N_{y,m-1}^{g} e^{-M_{m-1}^g/2} - \sum_{f} C_{f,y,m-1}^{g} \right) e^{-M_{m-1}^g/2} + \left( N_{ym}^{g} e^{-M_m^g/2} - \sum_{f} C_{fym}^{g} \right) e^{-M_m^g/2} \qquad \text{(App.10.I.9)}$$

The procedure above can however lead to problems in situations where the catch specified is not small relative to the resource biomass, and may lead to certain numbers-at-age going negative. To avoid such a situation arising, and indeed further to ensure that in any one year no more than 90% of any cohort can be taken by the fishery as a whole (as this would require an unrealistically large level of effort), the following procedure is then followed. First to see whether this situation has arisen, for each species and age, check that:

$$\left[ N_{ya}^{g} e^{-M_a^g/2} - \sum_{f} C_{fya}^{g} \right] \ge \left[ 0.1 N_{ya}^{g} e^{-M_a^g/2} \right] \qquad \text{(App.10.I.10)}$$

if $\left[N^{g}_{ya} e^{-M^{g}_{a}/2} - \sum_{f} C^{g}_{fya}\right] < \left[0.1 N^{g}_{ya} e^{-M^{g}_{a}/2}\right]$ for any age *a* then:

$$N^{*g}_{y,a} = N^{g}_{y*a} e^{-M^{g}_{a}/2} \qquad \text{(App.10.I.11)}$$

For each fleet in the following order: West Coast longline, South Coast longline, West Coast offshore, South Coast offshore, South Coast inshore and South Coast handline, go through equations App.10.I.12 to App.10.I.18:

**A**]. if $F^{para}_{fy} > 0.9$ and $F^{cap}_{fy} \leq 0.9$, otherwise go to **B**]

$$F^{'para}_{fy} = 0.9 \qquad \text{(App.10.I.12)}$$

$$F^{'cap}_{fy} = \frac{C_{fy} - 0.9 \sum_{g} \sum_{a=0}^{m} \tilde{w}^{para,g}_{fy,a+1/2} N^{*para,g}_{ya} S^{para,g}_{fya}}{\sum_{g} \sum_{a=0}^{m} \tilde{w}^{cap,g}_{fy,a+1/2} N^{*cap,g}_{ya} S^{cap,g}_{fya}} \qquad \text{(App.10.I.13)}$$

if $F^{'cap}_{fy} > 0.9$ then go to **C**].

**B**] if $F^{cap}_{fy} > 0.9$ and $F^{para}_{fy} \leq 0.9$

$$F^{'cap}_{fy} = 0.9 \qquad \text{(App.10.I.4)}$$

$$F^{'para}_{fy} = \frac{C_{fy} - 0.9 \sum_{g} \sum_{a=0}^{m} \tilde{w}^{cap,g}_{fy,a+1/2} N^{*cap,g}_{ya} S^{cap,g}_{fya}}{\sum_{g} \sum_{a=0}^{m} \tilde{w}^{para,g}_{fy,a+1/2} N^{*para,g}_{ya} S^{para,g}_{fya}} \qquad \text{(App.10.I.15)}$$

if $F^{'para}_{fy} > 0.9$ then go to **C**].

C] if $F^{para}_{fy} > 0.9$ and $F^{cap}_{fy} > 0.9$

$$F_{fy}^{'para} = 0.9 \text{ and } F_{fy}^{'cap} = 0.9 \qquad \text{(App.10.I.16)}$$

$$C_{fya}^{g} = N_{ya}^{*g} F_{fy}^{'} S_{fya}^{g} \qquad \text{(App.10.I.17)}$$

$$N_{y,a}^{'g} = N_{ya}^{*g} - C_{fya}^{g} \qquad \text{(App.10.I.18)}$$

In equations App.10.I.13, App.10.I.15 and App.10.I.17, $N_{y,a}^{*g}$ is replaced by $N_{y,a}^{'g}$.

Move to the next fleet and continue through all the fleets.

$$N_{y+1,a+1}^{g} = N_{ya}^{'g} e^{-M_a^g/2} \qquad \text{for } 0 \le a \le m-2 \qquad \text{(App.10.I.19)}$$

$$N_{y+1,m}^{g} = N_{y,m-1}^{'g} e^{-M_{m-1}^g/2} + N_{y,m}^{'g} e^{-M_m^g/2} \qquad \text{(App.10.I.20)}$$

**Step 4: Recruitment**

Future recruitments are provided by a Beverton-Holt or a modified (generalised) form of the Ricker stock-recruitment relationship, as specified for the OM and assuming a 50:50 sex-split at recruitment.

$$R_y^g = \frac{4hR_0 B_y^{♀,sp}}{K^{♀,sp}(1-h) + (5h-1)B_y^{♀,sp}} e^{(\varsigma_y - \sigma_R^2/2)} \qquad \text{(App.10.I.21)}$$

for the Beverton-Holt stock-recruitment relationship and

$$R_y^g = \alpha B_y^{♀,sp} \exp\left(-\beta\left(B_y^{♀,sp}\right)^{\gamma}\right) e^{(\varsigma_y - \sigma_R^2/2)} \qquad \text{(App.10.I.22)}$$

with

$$\alpha = R_0 \exp\left(\beta\left(K^{♀,sp}\right)^{\gamma}\right) \qquad \text{and} \qquad \beta = \frac{\ln(5h)}{\left(K^{♀,sp}\right)^{\gamma}\left(1-5^{-\gamma}\right)}$$

for the modified Ricker relationship.

Log-normal fluctuations are introduced by generating $\varsigma_y$ factors from $N\left(0,\sigma_R^2\right)$ where $\sigma_{\mathrm{R}}$ is estimated from the residuals of the model fit for years 1985 to 2004. $K^{sp}$, *h* (and $\gamma$ with the modified Ricker) are as estimated for that OM.

$B_y^{♀sp}$ is the female spawning biomass at the start of year *y*, computed as:

$$B_y^{♀,sp} = \sum_{a=1}^{m} f_a^{♀} w_a^{♀} N_{ya}^{♀} \qquad \text{(App.10.I.23)}$$

**Step 5: Generate data**

The information obtained in Steps 1 to 4 is used to generate values of the biomass indices in the form of species-disaggregated CPUE series (one for each coast and species) and survey indices of biomass (one for each coast and species). These biomass indices (CPUE and surveys) are generated from the OM, assuming the same error structures as in the past, as follows:

(a) Coast- and species-disaggregated CPUE series are generated from model estimates for corresponding mid-year exploitable biomass and catchability coefficients, with multiplicative lognormal errors incorporated where the associated variance is estimated within the OM concerned from past data. When computing the TAC for year *y*+1, such data are available to year *y*–1.

$$I_y^i = \hat{q}^i \hat{B}_{fy}^{ex} e^{\varepsilon_y^i} \qquad \text{(App.10.I.24)}$$

where

$$B_{fy}^{ex} = \sum_{g} \sum_{a=0}^{m} \tilde{w}_{fy,a+1/2}^{g} S_{fya}^{g} N_{ya}^{g} e^{-M_a^g/2} \left( 1 - \sum_{f} S_{fya}^{g} F_{fy} \Big/ 2 \right) \qquad \text{(App.10.I.25)}$$

$$\hat{\sigma}^i = \sqrt{1/n_i \sum_{y=1978}^{2008} \left( \ell n(I_y^i) - \ell n(\hat{I}_y^i) \right)^2} \qquad \text{and} \qquad \text{(App.10.I.26)}$$

$$\ell n\,\hat{q}^i = \frac{\sum\limits_{y=1978}^{2008}\left(\ell n I^i_y - \ell n \hat{B}^{ex}_{fy}\right)}{\sum\limits_{y=1978}^{2008} 1} \qquad \text{(App.10.I.27)}$$

$$\varepsilon^i_y \quad \text{from } N\left(0,\left(\sigma^i\right)^2\right) \qquad \text{(App.10.I.28)}$$

(b) Species-disaggregated biomass estimates from the West Coast summer and South Coast autumn surveys are generated from model estimates of mid-year survey biomass. Because the research survey vessel, the RV *Africana*, used new gear commencing in 2003/2004, estimates from that date are adjusted by a multiplicative bias when the new gear is used. For future projections it is assumed that each year the new gear is used (this is no restriction is practice, because even if gear is varied in future, a calibration factor assumed to be known exactly would be applied). Lognormal error variance includes the survey sampling variance with the CV set equal to the average historical value, plus survey additional variance (the variability that is not accounted for by sampling variability) as estimated within the OM concerned from past data. For the TAC for year *y*+1, such data are available for year *y*.

$$I^i_y = \hat{q}^i \hat{B}^{surv}_{fy} e^{\varepsilon^i_y} \qquad \text{(App.10.I.29)}$$

$$B^{surv}_y = \sum_g \sum_{a=0}^{m} \tilde{w}^{g,sum}_a S^{g,sum}_a N^g_{ya} \qquad \text{(App.10.I.30)}$$

for begin-year (summer) surveys, and

$$B^{surv}_y = \sum_g \sum_{a=0}^{m} \tilde{w}^{g,win}_{a+1/2} S^{g,win}_a N^g_{ya} e^{-M^g_a/2}\left(1-\sum_f S^g_{fya} F_{fy} \Big/ 2\right) \qquad \text{(App.10.I.31)}$$

for mid-year (spring, winter and autumn) surveys,

$\tilde{w}^{g,i}_a$ is the survey selectivity-weighted weight-at-age *a* of gender *g* for survey *i*, computed in the same manner as for the commercial selectivity-weight-at-age (equation

App.II.9) and taking account of the begin-year ($\tilde{w}^{g,sum}_{y,a}$ from $P^g_{a,l}$) or mid-year ($\tilde{w}^{g,win}_{y,a+1/2}$ from $P^g_{a+1/2,l}$) nature of the surveys.

$$\varepsilon^i_y \quad \text{from } N\left(0,\left(\sigma^i\right)^2\right) \tag{App.10.I.32}$$

where

$$\sigma^i = \sqrt{\ln(1+\overline{CV^i}^2)+\sigma_a^2} \tag{App.10.I.33}$$

The survey specific average CV ($\overline{CV^i}$) is computed over all the years available for that survey as:

$$\overline{CV^i} = \frac{\sum_y se^i_y / I^i_y}{\sum_y 1} \tag{App.10.I.34}$$

For *M. paradoxus*, $\overline{CV^i}$ is 0.185 and 0.372 for the West Coast summer and South Coast autumn surveys respectively, and for *M. capensis*, $\overline{CV^i}$ is similarly 0.178 and 0.112.

The reason for this difference in periods for which data are available is that the recommendation for a TAC, which applies over a calendar year (*y*+1), is required by October of the preceding year (*y*). By that time the results of the surveys conducted during year *y* will be available, but not for CPUE which pertains to the full calendar year *y*. Thus, care is taken in developing and testing the OMP that only data that would actually be available at the time a TAC recommendation is required are used. Furthermore, in order to project the resource biomass trajectory forward, the TAC needs to be disaggregated by species and by fleet.

As for the commercial selectivity, the survey selectivities are obtained under the assumption that the selectivity functions estimated for that OM remain constant.

**Step 6:**

Given the new CPUE indices $I_{y-1}^{i}$ and the new survey indices $I_{y}^{i}$ compute $TAC_{y+1}$ using the CMP.

**Step 7:**

Steps 1-6 are repeated for each future year in turn for as long a period as desired, and at the end of that period the performance of the candidate MP under review is assessed by considering statistics such as the average catch taken over the period and the final spawning biomass of the resource.

## 10.I.2 Performance Statistics

The following performance statistics, related to the objectives above, are computed for the CMP tested. Projections are conducted over 20 years.

Utilisation-related

- The median of the medium term average TAC: $\frac{1}{10}\sum_{y=2011}^{2020} C_y$ (for both species combined).
- The 2.5% PI of the lowest expected TAC (for both species combined) during the projection period.

TAC variability

- The median Average Annual Variation in TAC: $AAV = \frac{1}{20}\sum_{y=2011}^{2030} \left| C_y - C_{y-1} \right| / C_{y-1}$ .
- The probability of a decline in the TAC greater than 20% over the 2011-2013 period.
- The probability of a decline in the TAC greater than 20% over the 2012-2014 period.
- The median and 97.5% PI probability of a decline in the TAC greater than 20% over any consecutive three years for such periods commencing 2011-2028.

Resource status-related

- The 2.5% PI of $B^{sp}_{low} / B^{sp}_{2010}$: for each species, the lowest expected female spawning biomass during the projection period, relative to current (2010) level.
- The median of $B^{sp}_{2020} / B^{sp}_{MSY}$ : for each species, the expected female spawning biomass in 2020, relative to the Maximum Sustainable Yield level.

In addition, time trajectories are plotted for certain outputs from the projections, such as $C_y$ and $B^{sp}_y$.

## 10.I.3 Summary of data available to CMPs

The data available to a CMP to provide a TAC recommendation for year *y*+1 are:

- Catch data by species to year *y*-1
- CPUE indices by coast and species to year *y*-1
- Survey biomass estimates by coast and species to year *y*.

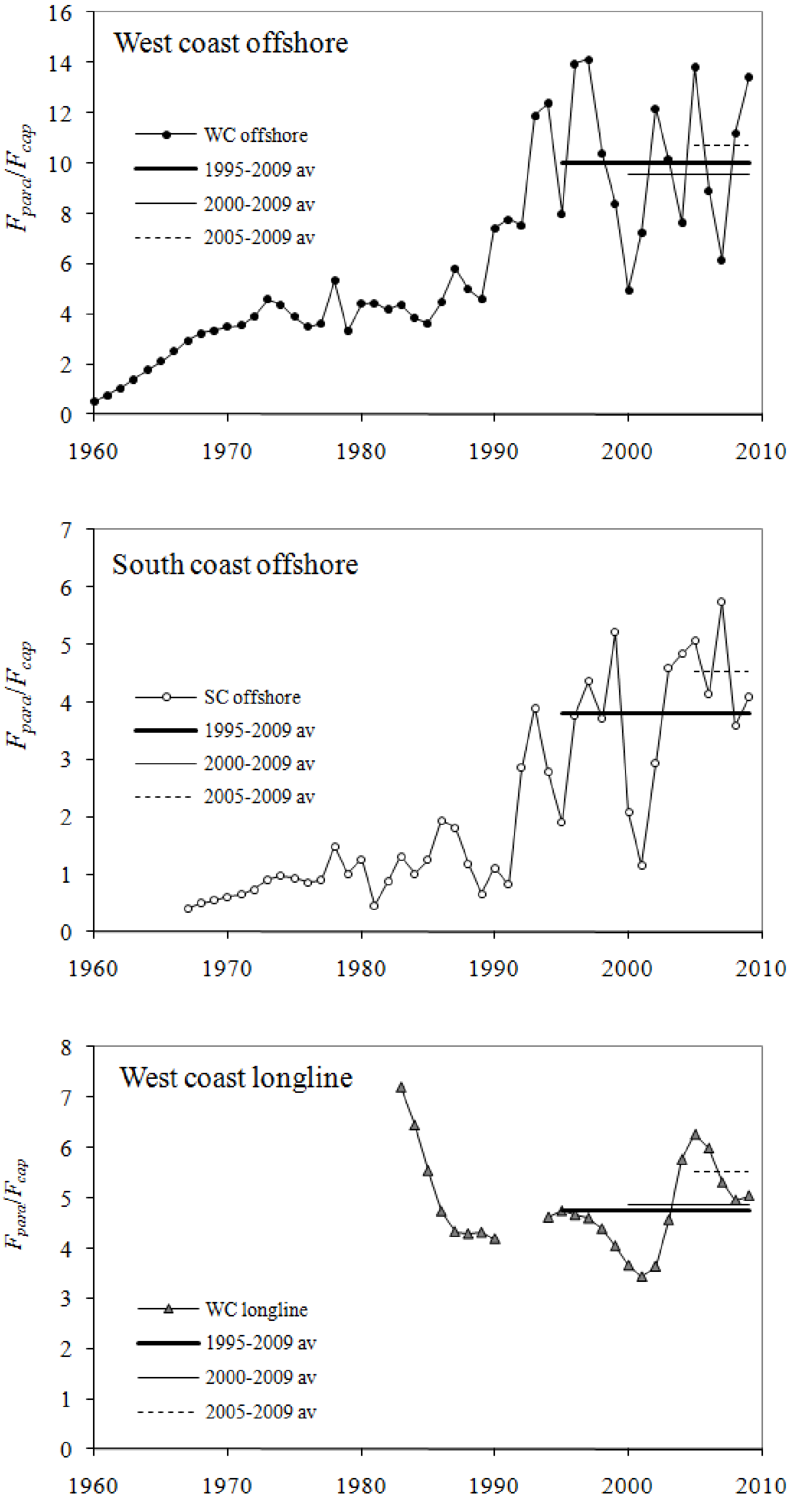


Figure App.10.I.1: Trends in past $F_{\text{ratio}}$ ($F_{\text{para}}/F_{\text{cap}}$) for the West and South Coast offshore trawl and West Coast longline fleet for the Reference Case assessment (RS1) within the Reference Set. The averages over1995-2009, 2000-2009 and 2005-2009 are also shown.

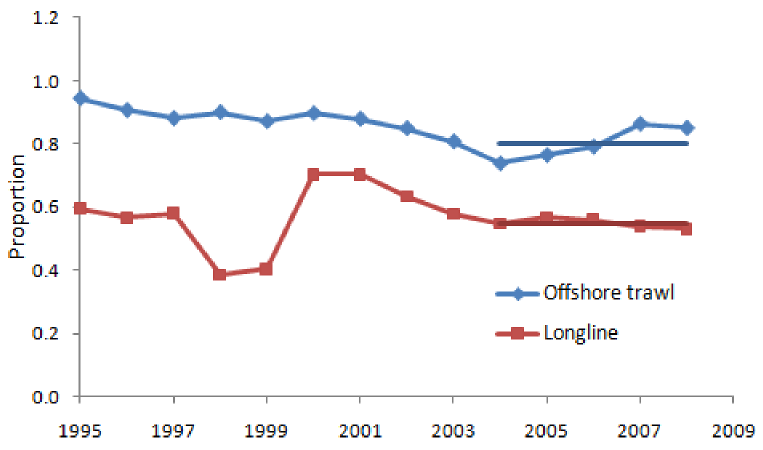


Figure App.10.I.2: Proportion of the species combined offshore trawl and longline catches taken on the West Coast. The averages over the last five years are also shown.

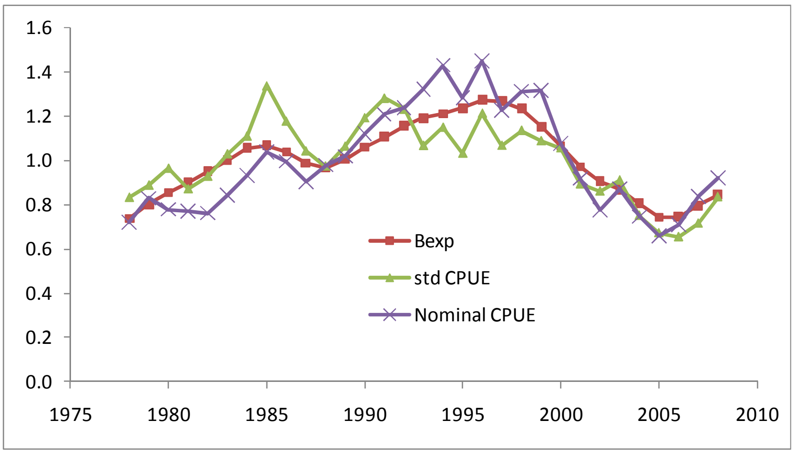


Figure App.10.I.3: Comparison of nominal CPUE (aggregated over species, gender and coasts), CPUE GLM-standardised as for coast- and species-specific data, and offshore trawl species- and coast-combined exploitable biomass in the past as estimated for the Reference Case assessment..

# APPENDIX 10.II

# 2010 Operational Management Procedure Specifications

## 10.II.1 Introduction

The algorithm for OMP-2011 to provide TAC recommendations for the South African *Merluccius paradoxus* and *M. capensis* resources is empirical. It combines an increase or decrease of the TAC in relation to a) the magnitude of recent trends in CPUE and survey biomass estimates for both species and b) the relative level of recent CPUE and survey biomass estimates compared to a target level. The basis for the associated computations is set out below, with the tuning parameters given in Table App.10.II.1.

## 10.II.2 The 2011 OMP

The formula for computing the TAC recommendation is as follows:

$$TAC_y = C_y^{para} + C_y^{cap} \qquad \text{(App.10.II.1)}$$

with

$$C_y^{spp} = w_y C_{y-1}^{*spp}\left[1 + \lambda_{up/down}\left(s_y^{spp} - T_y^{spp}\right)\right] + \left(1 - w_y\right)\left[a^{spp} + b^{spp}\left(J_y^{spp} - 1\right) - Pen_y^{spp}\right] \qquad \text{(App.10.II.2)}$$

where

$TAC_y$ is the total TAC recommended for year *y*,

$C_y^{spp}$ is the intended species-disaggregated TAC for year *y*,

$C_{y-1}^{*spp}$ is the achieved catch[4] of species *spp* in year *y*-1,

---

[4] Implemented by applying the species ratio of the catch in year *y*-2 to the TAC for year *y*-1, as the species ratio for year *y*-1 would not yet be known by the time at which a recommendation for the TAC for year *y* would be required.

$w_y$ is a year-dependent tuning parameter,

$\lambda_{up/down}$ are tuning parameters; $\lambda_{up}$ is used if $s_y^{spp} \geq 0$ and $\lambda_{down}$ is used if $s_y^{spp} < 0$,

$T_y^{spp}$ is the year-dependant target rate of increase for species *spp*,

$s_y^{spp}$ is a measure of the immediate past trend in the biomass indices for species *spp* as available to use for calculations for year *y*,

$a^{spp}$, $b^{spp}$, $c^{spp}$ and $p^{spp}$ are tuning parameters, and

$$Pen_y^{spp} = \begin{cases} 0 & \text{if } J_y^{spp} \geq p^{spp} \\ c^{spp}\left(J_y^{spp} - p^{spp}\right)^2 & \text{if } J_y^{spp} < p^{spp} \end{cases} \qquad \text{(App.10.II.3)}$$

where

$J_y^{spp}$ is a measure of the immediate past level in the biomass indices for species *spp* as available to use for calculations for year *y*.

### 10.II.2.1 Measure of recent trend

The trend measure $s_y^{spp}$ is computed as follows from the species- and coasts-disaggregated GLM-CPUE ($I_y^{WC\_CPUE,spp}$ and $I_y^{SC\_CPUE,spp}$), West Coast summer survey ($I_y^{WC\_surv,spp}$) and South Coast autumn survey ($I_y^{SC\_surv,spp}$) indices:

- linearly regress $\ln I_y^{WC\_CPUE,spp}$ and $\ln I_y^{SC\_CPUE,spp}$ *vs* year *y'* for $y' = y - p - 1$ to $y' = y - 2$, to yield two regression slope values $s_y^{WC\_CPUE,spp}$ and $s_y^{SC\_CPUE,spp}$,
- linearly regress $\ln I_y^{WC\_surv,spp}$ and $\ln I_y^{SC\_surv,spp}$ *vs* year *y'* for $y' = y - p$ to $y' = y - 1$, to yield two regression slope values $s_y^{WC\_surv,spp}$ and $s_y^{SC\_surv,spp}$,

where *p*=6 is the length of the periods considered for these regressions. Note that the reason the trend for surveys is calculated for a period moved one year later than for CPUE is that by the time of year that the TAC recommendation would be computed for the following year, survey results for the current year would be known, but not CPUE as fishing for the year would not yet have been completed. Note also that surveys carried out using the old gear are made comparable to those carried out using the new gear by multiplying them by a species specific calibration factor (0.95 for *M. paradoxus* and 0.8 for *M. capensis*).

Then:

$$s_y^{para} = \left(s_y^{WC\_CPUE,para} + 0.75 s_y^{SC\_CPUE,para} + 0.5 s_y^{WC\_surv,para} + 0.25 s_y^{SC\_surv,para}\right)\Big/ 2.5$$

(App.10.II.4)

$$s_y^{cap} = \left(s_y^{WC\_CPUE,cap} + 0.75 s_y^{SC\_CPUE,cap} + 0.5 s_y^{WC\_surv,cap} + s_y^{SC\_surv,cap}\right)\Big/ 3.25$$

(App.10.II.5)

### 10.II.2.2 Measure of recent level

The measure of the immediate past level $J_y^{spp}$ in the biomass indices is computed as follows:

$$J_y^{para} = \frac{1.0 J_y^{WC\_CPUE,para} + 0.75 J_y^{SC\_CPUE,para} + 0.5 J_y^{WC\_surv,para} + 0.25 J_y^{SC\_surv,para}}{2.5}$$

(App.10.II.6)

$$J_y^{cap} = \frac{1.0 J_y^{WC\_CPUE,cap} + 0.75 J_y^{SC\_CPUE,cap} + 0.5 J_y^{WC\_surv,cap} + 1.0 J_y^{SC\_surv,cap}}{3.25}$$

(App.10.II.7)

with

$$J_y^{WC\_CPUE,spp} = \frac{\sum_{y'=y-4}^{y-2} I_y^{WC\_CPUE,spp}}{\theta^{spp} \sum_{y=2006}^{2008} I_y^{WC\_CPUE,spp}}$$

(App.10.II.8)

$$J_y^{SC\_CPUE,spp} = \frac{\sum_{y'=y-4}^{y-2} I_y^{SC\_CPUE,spp}}{\theta^{spp} \sum_{y=2006}^{2008} I_y^{SC\_CPUE,spp}}$$

(App.10.II.9)

$$J_y^{WC\_surv,spp} = \frac{\sum_{y'=y-3}^{y-1} I_y^{WC\_surv,spp}}{\theta^{spp} \sum_{y=2007}^{2009} I_y^{WC\_surv,spp}} \quad \text{and} \qquad \text{(App.10.II.10)}$$

$$J_y^{SC\_surv,spp} = \frac{\sum_{y'=y-3}^{y-1} I_y^{SC\_surv,spp}}{\theta^{spp} \sum_{y=2007}^{2009} I_y^{SC\_surv,spp}} \qquad \text{(App.10.II.11)}$$

with

$\theta^{para}$= 1.67 and $\theta^{cap}$ = 1.50.

### 10.II.2.3 Maximum allowable change in TAC

While the maximum allowable annual increase in TAC is 10%, the maximum allowable decrease in TAC from one year to the next is:

$$MaxDecr_y = \begin{cases} 5\% & \text{if } J_y > Q_{\min} \\ \text{linear between 5\% and 25\%} & \text{if } Q_{\min} - 0.2 \le J_y \le Q_{\min} \\ 25\% & \text{if } J_y < Q_{\min} - 0.2 \end{cases} \qquad \text{(App.10.II.12)}$$

where

$$J_y = \frac{J_y^{para} + J_y^{cap}}{2} \qquad \text{(App.10.II.13)}$$

and

$Q_{\min}$ is a tuning parameter.

## 10.II.3 Procedure in event of missing data

### 10.II.3.1 CPUE data

Non-availability of data to compute the GLM-standardised CPUE series for each species is not anticipated.

### 10.II.3.2 Survey data

a) If at most two of the four survey estimates are not available in a given year, the computations continue as indicated, with the missing data omitted from the regression estimates of *slope*.

b) If more than two such estimates are missing, or if for more than one survey two years have been missed, computations will continue on the basis in a), but an OMP review will commence immediately.

Table App.10.II.1: Tuning parameters for OMP-2011

<table>
<tr><th></th><th><i>M. paradoxus</i></th><th><i>M. capensis</i></th></tr>
<tr><td>$\lambda_{up}$</td><td colspan="2">1.25</td></tr>
<tr><td>$\lambda_{down}$</td><td colspan="2">1.50</td></tr>
<tr><td>$T_y^{spp}$</td><td>0.75% if $y < 2015$<br>linear between 0.75% and 0% $2015 \le y \le 2018$<br>0% if $y \ge 2019$</td><td>0%</td></tr>
<tr><td>$w_y$</td><td colspan="2">1 if $y \le 2011$<br>linear between 1 and 0.5 $2012 \le y \le 2015$<br>0.5 if $y \ge 2016$</td></tr>
<tr><td>$a^{spp}$</td><td>104.5</td><td>40</td></tr>
<tr><td>$b^{spp}$</td><td>60</td><td>20</td></tr>
<tr><td>$c^{spp}$</td><td>180</td><td>20</td></tr>
<tr><td>$p^{spp}$</td><td>0.75</td><td>0.75</td></tr>
<tr><td>$Q_{\min}$</td><td colspan="2">0.75</td></tr>
</table>

# APPENDIX 10.III

# Procedures for deviating from OMP output for the recommendation for a TAC, and for initiating an OMP review

## 10.III.1. Metarule Process

Metarules can be thought of as "rules" which pre-specify what should happen in unlikely, Exceptional Circumstances when application of the TAC generated by the OMP is considered to be highly risky or highly inappropriate. Metarules are not a mechanism for making small adjustments, or 'tinkering' with the TAC from the OMP. It is difficult to provide firm definitions of, and to be sure of including all possible, Exceptional Circumstances. Instead, a process for determining whether Exceptional Circumstances exist is described below (see Figure App.10.III.1). The need for invoking a metarule should be evaluated by the relevant DAFF Scientific Working Group (hereafter indicated by SWG), but only provided that appropriate supporting information is presented so that it can be reviewed at a SWG meeting.

### 10.III.1.1 Description of Process to Determine Whether Exceptional Circumstances Exist

While the broad circumstances that may invoke the metarule process can be identified, it is not always possible to pre-specify the data that may trigger a metarule. If a SWG Member or Observer, or DAFF Management, is to propose an Exceptional Circumstances review, then such person(s) must outline in writing the reasons why they consider that Exceptional Circumstances exist, and must either indicate where the data, information or analyses are to be found supporting the review, or must supply those data, information or analyses in advance of the SWG meeting at which their proposal is to be considered.

Every year the SWG will:

- Review population and fishery indicators, and any other relevant data or information on the population, fishery and ecosystem, and conduct a simple routine updated assessment (likely no more than core reference set models used in the OMP testing refitted taking a further year's data into account).
- On the basis of this, determine whether there is evidence for Exceptional Circumstances.

Examples of what might constitute an exceptional circumstance in the case of hake include, but are not necessarily limited to:

- Survey estimates of biomass that are appreciably outside the bounds predicted in the OMP testing.
- Standardized CPUE trends that are appreciably outside the bounds predicted in the OMP testing.
- Catch species composition in major components of the fishery or surveys that differ markedly from previous patterns (and so may reflect appreciable changes in selectivity).

Every two years the SWG will:

- Conduct an in depth stock assessment (more intensive than the annual process above, and in particular including the conduct of a range of sensitivity tests).
- On the basis of the assessment, indicators and any other relevant information, determine whether there is evidence for Exceptional Circumstances.

The primary focus for concluding that Exceptional Circumstances exist is if the population assessment/indicator review process provides results appreciably outside the range of simulated population and/other other indicator trajectories considered in OMP evaluations. This includes the core (Reference case or set of) operating models used for these evaluations, and likely also (though subject to discussion) the operating models for the robustness tests for which the OMP was considered to have shown adequate performance. Similarly, if the review process noted regulatory changes likely to effect appreciable modifications to outcomes predicted in terms of the assumptions used for projections in the OMP evaluations (e.g. as a result, perhaps, of size limit changes or closure of areas), or changes to the nature of the data collected for input to the OMP beyond those for which allowance may have been made in those evaluations, this would constitute grounds for concluding that Exceptional Circumstances exist in the context of continued application of the current OMP.

Every year, IF the SWG concludes that there is no or insufficient evidence for Exceptional Circumstances, the SWG will:

- Report to the Director Resources Research, DAFF that Exceptional Circumstances do not exist.

IF the SWG has agreed that Exceptional Circumstances exist, the SWG will:

- Determine the severity of the Exceptional Circumstances.
- Follow the "Process for Action" described below.

### 10.III.1.2 Specific issues that will be considered annually (regarding Underlying Assumptions of the Operating Models (OMs) for the OMP Testing Process)

The following critical aspects of assumptions underlying the OMs for hake need to be monitored after OMP implementation. Any appreciable deviation from these underlying assumptions may constitute an exceptional circumstance (i.e. potential metarule invocation) and will require a review, and possible revision, of the OMP:

- Whether over recent years the species splits of catches from the major fisheries differ substantially from the species splits considered in projections in the OMP testing.
- Whether selectivities-at-length for the major fisheries differ substantially from assumptions made to generate operating model projections.
- Whether standardised CPUE and survey biomass estimates are within the bounds indicated in operating model projections, where bounds here and in similar cases following shall be taken to be the 2.5%ile and 97.5%ile of projections under the Reference Set a (RSa) of operating models.

- Whether future recruitment levels are within the bounds projected by the RS1 operating models.
- Whether new data suggest appreciably increased plausibility of the RSb scenarios which reflect a much more depleted *M. capensis* population than is the case under RSa.
- Whether the "survey-standardised-CPUE discrepancy statistic" defined below for each species as:

  $$D_y^{WC\_surv,spp} = \Delta I_y^{WC\_surv,spp} - \frac{\left(\Delta I_y^{WC\_CPUE,spp} + \Delta I_y^{SC\_CPUE,spp}\right)}{2}$$

  $$D_y^{SC\_surv,spp} = \Delta I_y^{SC\_surv,spp} - \frac{\left(\Delta I_y^{WC\_CPUE,spp} + \Delta I_y^{SC\_CPUE,spp}\right)}{2}$$

  where

  $$\Delta I_y^i = \frac{\left(I_{y+1}^i - I_y^i\right)}{I_y^i}$$

  falls outside the bounds indicating in the OMP testing.
- Whether updates of major data sets or ageing practices indicate substantial differences from what were used to condition the operating models for the OMP testing.
- Whether there have been a series of substantial differences between TACs allocated and the catches subsequently made.
- Whether fishing regulations and/or strategies have changed substantially, and in a manner such that continuing use of the agreed GLM-standardisation procedures would likely introduce substantial bias in resource biomass trend estimates based on CPUE indices.
- Whether new data or information suggest a substantial revision of estimates of stock status or of the spawning biomass at MSY which is the target reference point for the fishery.
- Whether updated assessments suggest that the spawning biomass for the *M. paradoxus* population has fallen below its 2007 level, which will be considered a limit reference point for the fishery. Given that the OMP intends recovery of this population, an

upward revision of this reference point will be considered at the next four-yearly OMP review.

A guide as to what constitutes "substantial" is a change that would alter the recommended TAC by more than 3%.]

### 10.III.1.3 Description of Process for Action

If making a determination that there is evidence of Exceptional Circumstances, the WG will with due promptness:

- Consider the severity of the Exceptional Circumstances (for example, how severely "out of bounds" are the recent CPUEs and survey biomass estimates or recruitment estimates).
- Follow the principles for action (see examples below).
- Formulate advice on the action required (this could include an immediate change in TAC, a review of the OMP, the relatively urgent collection of ancillary data, or conduct of analyses to be reviewed at a further SWG meeting in the near future).
- Report to the Director Resources Research, DAFF that Exceptional Circumstances exist and provide advice on the action to take.

The Director Resources Research, DAFF will:

- Consider the advice from the SWG.
- Decide on the action to take, or recommendations to make to his/her principals.

### 10.III.1.4 Examples of 'Principles for Action'

If the risk is to the resource, or to dependent or related components of the ecosystem, principles may be:

- The OMP-derived TAC should be an upper bound.
- Action should be at least an x% decrease in the TAC output by the OMP, depending on severity.

If the risk is to socio-economic opportunities within the fishery, principles may be:

- The OMP-derived TAC should be a minimum.
- Action should be at least a y% increase in the TAC output by the OMP, depending on severity.

For certain categories of Exceptional Circumstances, specific metarules may be developed and pre-agreed for implementation should the associated circumstances arise (for example, as has been the case for OMP's for the sardine-anchovy fishery where specific modified TAC algorithms come into play if biomass estimates from surveys fall below pre-specified thresholds). Where such development is possible, it is preferable that it be pursued.

## 10.III.2. Regular OMP Review and Revision Process

The procedure for regular review and potential revision of the OMP is the process for updating and incorporating new data, new information and knowledge into the management procedure, including the operating models (OMs) used for testing the procedure. This process should happen on a relatively long time-scale to avoid jeopardising the performance of the OMP, but can be initiated at any time if the SWG considers that there is sufficient reason for this, and that the effect of the revision would be substantial. During the revision process the OMP should still be used to generate TAC recommendations unless a metarule is invoked.

### 10.III.2.1 Description of Process for Regular Review (see Figure App.10.III.2)

Every year the SWG will:

- Consider whether the procedure for Metarule Process has triggered a review/revision of the OMP. Note that if proposals by a SWG Member or Observer, or DAFF Management, for an Exceptional Circumstances review include suggestions for an OMP review and possible revision, they must outline in writing the reasons why they consider this necessary, and must either indicate where the data, information or analyses are to be found supporting their proposed review, or must supply those data or analyses in advance of the SWG meeting at which their proposal is to be considered.

This includes the possibility of a suggested improvement in the manner in which the OMP calculates catch limitation recommendations; this would need to be motivated by reporting results for this amended OMP when subjected to the same set of trials as were used in the selection of the existing OMP, and arguing that improvements in anticipated performance were evident.

Every two years the SWG will:

- Conduct an in depth stock assessment and review population, fishery and related ecosystem indicators, and any other relevant data or information on the population, fishery and ecosystem.
- On the basis of this, determine whether the assessment (or other) results are outside the ranges for which the OMP was tested (note that evaluation for Exceptional Circumstances would be carried out in parallel with this process; see procedures for the Metarule Process), and whether this is sufficient to trigger a review/revision of the OMP.
- Consider whether the procedure for the Metarule Process triggered a review / revision of the OMP.

Every four years since the last revision of the OMP the SWG will:

- Review whether enough has been learnt to appreciably improve/change the operating models (OMs), or to improve the performance of the OMP, or to provide new advice on tuning level (chosen to aim to achieve management objectives).

On the basis of this, determine whether the new information is sufficient to trigger a review/revision of the OMP.

In any year, IF the SWG concludes that there is sufficient new information to trigger a review/revision of the OMP, the SWG will:

- Outline the work plan and timeline (e.g. over a period of one year) envisaged for conducting a review.
- Report to the Director Resources Research, DAFF that a review/revision of the OMP is required, giving details of the proposed work plan and timeline.

- Advise the Director Resources Research, DAFF that the OMP can still be applied while the revision process is being completed (unless Exceptional Circumstances have been determined to apply and a metarule invoked).

In any year, IF the SWG concludes that there is no need to commence a review/revision of the OMP, the SWG will:

Report to the Director Resources Research, DAFF that a review/revision of the OMP is not yet required.

The Director Resources Research, DAFF will:

- Review the report from the SWG.
- Decide whether to initiate the review/revision process.

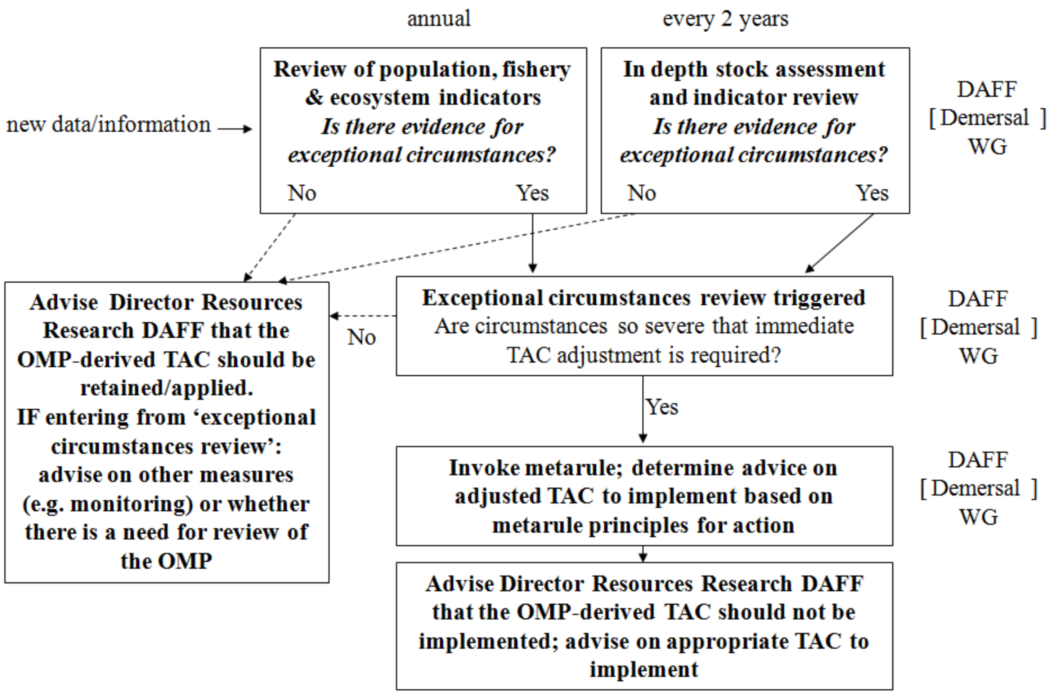


Figure App.10.III.1: Flowchart for Metarules Process

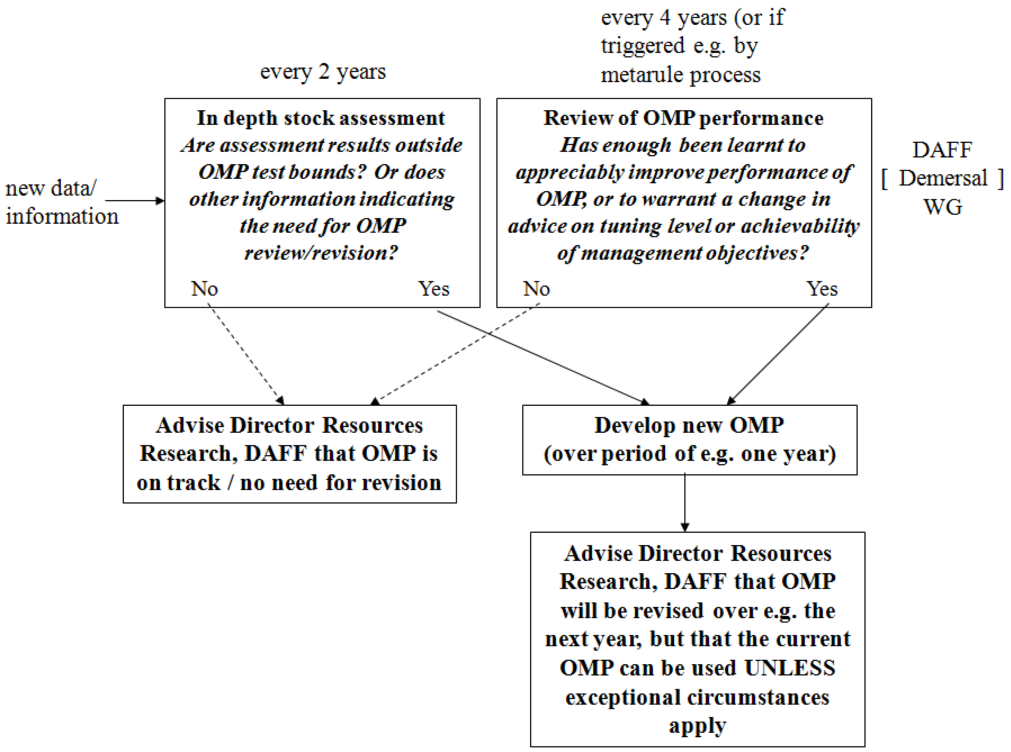


Figure App.10.III.2: Flowchart for Regular Review and Revision Process.