Hake Candidate Management Procedures Testing Methodology

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Note: The symbols used in the algebraic specifications below are as defined in Rademeyer and Butterworth, 2013.

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 (2014) numbers-at-age

The components of the numbers-at-age vector for each gender and species at the start of 2014 are obtained from the MLE of an assessment of the resource, assuming a total catch in 2013 equal to the TAC set for that year and split between species, coast and fleet using the 2012 catch ratio. Note that the catch data input to the assessments used to develop the OMs extended only to 2012.

Error is included for numbers-at-ages 0 to 3 because these are poorly estimated in the assessment given limited information on these year-classes:, i.e.:

$$N^g_{2010,a} \rightarrow N^g_{2010,a} e^{\varepsilon_a} \qquad \varepsilon_a \text{ from } N\left(0, \left(\sigma_R\right)^2\right),$$

where σ_R is the standard deviation of the stock-recruitment residuals estimated by the OM for the years 1985 to 2009 (the last year before shrinking of SR residuals). Note that the residuals each year are assumed to be gender-independent.

Step 2: Catch

These numbers-at-age are projected one year forward at a time given a catch for the year concerned: C_y which is 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 fleet:
The total TAC recommended by the CMP is divided in fixed proportions among the various fleet and coasts, using the average of the 2008-2012 values, i.e.:

West coast offshore trawl: 73.2%;
South coast offshore trawl: 15.8%;
Inshore trawl: 4.3%;
West coast longline: 4.2%;
South coast longline: 2.1%; and
Handline: 0.2%.

Catch by species and gender:

Although the annual catch (TAC) generated by the CMP can be species-disaggregated, the TAC recommended by the OMP 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 and gender, it is assumed that for each fleet the species and gender ratios of the fishing mortality remain the same, i.e. that the current pattern of fishing remains approximately unchanged over the projection period. For each fleet (omitting the fleet and year subscripts *f* and *y*) the species ratios are given by:

$F_{ratio}^{males} = F^{para,males} \big/ F^{cap,males}$ and $F_{ratio}^{females} = F^{para,females} \big/ F^{cap,females}$,

and the gender ratios by:

$F_{ratio}^{para} = F^{para,males} \big/ F^{para,females}$ and $F_{ratio}^{cap} = F^{cap,males} \big/ F^{cap,females}$.

Figure 1 shows plots of estimates of these ratios for the fleets concerned, together with the average over recent (2009-2013) period, for the central OM within the Reference Set (RS1). Given that there is variability from year to year evident in these plots, 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 age:

C_{fya}^{g} is obtained by assuming that S_{fyl}^{g} , $P_{a+1/2,l}^{g}$ and $\tilde{w}_{a+1/2}^{g}$ stay constant in the future as estimated in the OM, and therefore that:

$$S_{fya}^{g} = \sum_{l} S_{fyl}^{g} P_{a+1/2,l}^{g} \qquad (1)$$

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.:

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

where θ_a , l_∞ , t_0 and κ are as estimated in the OM for each species and gender.

From this it follows that:

$$C_y = \sum_s \sum_g \sum_{a=0}^{m} \tilde{w}^{s,g}_{ya+1/2} \; N^{s,g}_{ya} e^{-M^{s,g}_a/2} F^{s,g}_y S^{s,g}_{ya} = \sum_s \sum_g F^{s,g}_y B^{\exp,s,g}_y \qquad (3)$$

To obtain the gender- and species-specific fishing mortality for each fleet (still leaving out the fleet *f* subscript for ease of reading), we use the ratio of the fishing mortalities to rewrite all the fishing mortalities in terms of $F^{cap,males}_y$:

$$F^{para,males}_y = F^{cap,males}_y F^{males}_{ratio} \qquad (4)$$

$$F^{para,females}_y = F^{females}_{ratio} F^{cap,females}_y = F^{females}_{ratio} \; F^{cap,males}_y \big/ F^{cap}_{ratio} \qquad (5)$$

$$F^{cap,females}_y = F^{cap,males}_y \big/ F^{cap}_{ratio} \qquad (6)$$

so that:

$$F^{cap,males}_y = \frac{C^{tot}_y}{\left[F^{males}_{ratio} B^{\exp,para,males}_y + \frac{F^{females}_{ratio}}{F^{cap}_{ratio}} B^{\exp,para,females}_{fy} + B^{\exp,cap,males}_{fy} + \frac{1}{F^{cap}_{ratio}} B^{\exp,para,females}_{fy} \right]} \qquad (7)$$

and hence that

$$C^g_{ya} = N^g_{ya} e^{-M^g_a/2} F^g_y S^g_{ya} \qquad (8)$$

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

$$N^g_{y+1,0} = R^g_{y+1} \qquad (9)$$

$$N^g_{y+1,a+1} = \left(N^g_{ya} e^{-M^g_a/2} - \sum_f C^g_{fya} \right) e^{-M^g_a/2} \qquad \text{for } 0 \le a \le m-2 \qquad (10)$$

$$N^g_{y+1,m} = \left(N^g_{y,m-1} e^{-M^g_{m-1}/2} - \sum_f C^g_{f,y,m-1} \right) e^{-M^g_{m-1}/2} + \left(N^g_{ym} e^{-M^g_m/2} - \sum_f C^g_{fym} \right) e^{-M^g_m/2} \qquad (11)$$

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 in Appendix A is then followed.

Step 4: Recruitment

Future recruitments are provided by a Beverton-Holt, a modified 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.

$$R^g_y = \frac{4hR_0 B^{♀,sp}_y}{K^{♀,sp}(1-h) + (5h-1) B^{♀,sp}_y} e^{(\varsigma_y - \sigma^2_R/2)} \qquad (12)$$

for the Beverton-Holt stock-recruitment relationship,

$$R_y^g = \begin{cases} \alpha B_y^{♀,sp} \exp\left(-\beta\left(B_y^{♀,sp}\right)^{\gamma}\right) e^{(\varsigma_y - \sigma_R^2/2)} & \text{if } B_y^{♀,sp} \geq B_{\min}^{♀,sp} \\ \alpha B_y^{♀,sp} \exp\left(-\beta\left(B_{\min}^{♀,sp}\right)^{\gamma}\right) e^{(\varsigma_y - \sigma_R^2/2)} & \text{if } B_y^{♀,sp} < B_{\min}^{♀,sp} \end{cases} \tag{13}$$

for the modified Beverton-Holt relationship, and

$$R_y^g = \alpha B_y^{♀,sp} \exp\left(-\beta\left(B_y^{♀,sp}\right)^{\gamma}\right) e^{(\varsigma_y - \sigma_R^2/2)} \tag{14}$$

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 ς_y factors from $N\left(0, \sigma_R^2\right)$ where σ_R is estimated from the residuals of the model fit for years 1985 to 2009. K^{sp}, *h* (and γ with the modified Ricker) are as estimated for that OM.

As in the past, the future residuals (ς_y) have been taken to be uncorrelated. However given the autocorrelation evident in the most recent assessments [Rademeyer and Butterworth, 2014], it is suggested that this should be taken forward into the projections. For the RC, this autocorrelation is 0.18 for *M. paradoxus* and 0.52 for *M. capensis*.

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). The 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.

$$I_y^i = \hat{q}^i \hat{B}_{fy}^{ex} e^{\varepsilon_y^i} \tag{15}$$

where

$$B_{fy}^{ex} = \sum_g \sum_{a=0}^{m} \tilde{w}_{fy,a+1/2}^g S_{fya}^g N_{ya}^g e^{-M_a^g/2} \left(1 - \sum_f S_{fya}^g F_{fy} \Big/ 2\right) \tag{16}$$

$$\hat{\sigma}^i = \sqrt{1/n_i \sum_{y=1978}^{2012} \left(\ell n(I_y^i) - \ell n(\hat{I}_y^i)\right)^2} \qquad \text{and} \tag{17}$$

$$\ell n\,\hat{q}^i = \frac{\sum_{y=1978}^{2012}\left(\ell n I_y^i - \ell n \hat{B}_{fy}^{ex}\right)}{\sum_{y=1978}^{2012} 1} \tag{18}$$

$$\varepsilon_y^i \quad \text{from } N\left(0,\left(\sigma^i\right)^2\right) \tag{19}$$

Correlation is assumed between the species indices on each coast, i.e. for *M. capensis*:

$$\varepsilon_y^{i,cap} = \rho_{CPUE}^i \varepsilon_y^{i,para} + \lambda_y^{i,cap}\sqrt{1-\left(\rho_{CPUE}^i\right)^2} \tag{20}$$

$$\lambda_y^i \quad \text{from } N\left(0,\left(\sigma^i\right)^2\right) \tag{21}$$

ρ_{CPUE}^i are computed from the past series: $\rho_{CPUE}^{WC} = 0.382$ and $\rho_{CPUE}^{SC} = 0.486$

(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 in 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*.

$$I_y^i = \hat{q}^i \hat{B}_{fy}^{surv} e^{\varepsilon_y^i} \tag{22}$$

$$B_y^{surv} = \sum_g \sum_{a=0}^{m} \tilde{w}_a^{g,sum} S_a^{g,sum} N_{ya}^g \tag{23}$$

for begin-year (summer) surveys, and

$$B_y^{surv} = \sum_g \sum_{a=0}^{m} \tilde{w}_{a+1/2}^{g,win} S_a^{g,win} N_{ya}^g e^{-M_a^g/2}\left(1-\sum_f S_{fya}^g F_{fy} \Big/ 2\right) \tag{24}$$

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

$$\varepsilon_y^i \quad \text{from } N\left(0,\left(\sigma^i\right)^2\right) \tag{25}$$

where

$$\sigma^i = \sqrt{\ln(1+\overline{CV^i}^2) + \sigma_a^2} \tag{26}$$

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

$$\overline{CV^i} = \frac{\sum_y se_y^i / I_y^i}{\sum_y 1} \qquad (27)$$

For *M. paradoxus*, $\overline{CV^i}$ is 0.202 and 0.404 for the West Coast summer and South Coast autumn surveys respectively, and for *M. capensis*, $\overline{CV^i}$ is similarly 0.251 and 0.162.

As for the CPUE series, correlation is assumed between the species indices on each coast, i.e. for *M. capensis*:

$$\varepsilon_y^{i,cap} = \rho_{surv}^i \varepsilon_y^{i,para} + \lambda_y^{i,cap} \sqrt{1-\left(\rho_{surv}^i\right)^2} \qquad (28)$$

$$\lambda_y^i \quad \text{from } N\left(0, \left(\sigma^i\right)^2\right) \qquad (29)$$

ρ_{surv}^i are computed from the past series: $\rho_{surv}^{WC} = 0.188$ and $\rho_{surv}^{SC} = -0.001$

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.

2 Performance Statistics

The following performance statistics (median and 95% probability intervals), related to the objectives above, are computed for the CMP tested. Projections are conducted over 20 years.

Utilisation-related

- The TAC (for both species combined) in 2015, 2016 and 2017;

- The medium term average TAC: $\frac{1}{10}\sum_{y=2015}^{2024} C_y$ (for both species combined).
- The lowest expected TAC (for both species combined) during the projection period.
- E_{2024}/E_{2013}: a measure of effort (for both species combined) in 2024 relative to 2013 level, where $E_y = C_y^{tot} \big/ \left(B_y^{\exp,para} + B_y^{\exp,cap}\right)$

  Note: For 2013, the catch is taken as the TAC for that year as the actual catch is not available at the time of calculation.

TAC variability

- The Average Annual Variation in TAC: $AAV = \frac{1}{20}\sum_{y=2015}^{2034} \left|C_y - C_{y-1}\right| / C_{y-1}$.
- The probability of a decline in the TAC greater than 20% over the 2015-2017 period.
- The probability of a decline in the TAC greater than 20% over the 2016-2018 period.
- The probability of a decline in the TAC greater than 20% over any consecutive three years for such periods commencing 2015-2032.

Resource status-related

- $B_{low}^{sp}/B_{2014}^{sp}$: for each species, the lowest expected female spawning biomass during the projection period, relative to current (2014) level;
- $B_{low}^{sp}/B_{2007}^{sp}$: for each species, the lowest expected female spawning biomass during the projection period, relative to 2007 level;
- $B_{2024}^{sp}/B_{MSY}^{sp}$: for each species, the expected female spawning biomass in 2024, 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_y^{sp} .

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*.
  - Africana survey data are assumed to become available again from January 2015.
  - Baseline CMP projections will use the survey estimates derived from a calibration of the Nansen survey in January 2013 [Fairweather *et al.*, 2013; Rademeyer, 2013], but thereafter assume no survey estimates available for autumn 2013 and throughout 2014.
  - The CMPs input an overall weighted average of CPUE and survey estimates of abundance, where each of those values is itself an average over a number of years into the immediate past. Given the absence of some survey estimates as indicated above, the following rules will apply:

a) If at least two years of surveys are available from the range of years over which an average is taken for that index of abundance, the average of the available values will be used.

b) If only one or no surveys are available from that range, the index will be omitted from the overall weighted average index input to the CMP, with this index instead weighting over only non-excluded indices for that year.

REFERENCES

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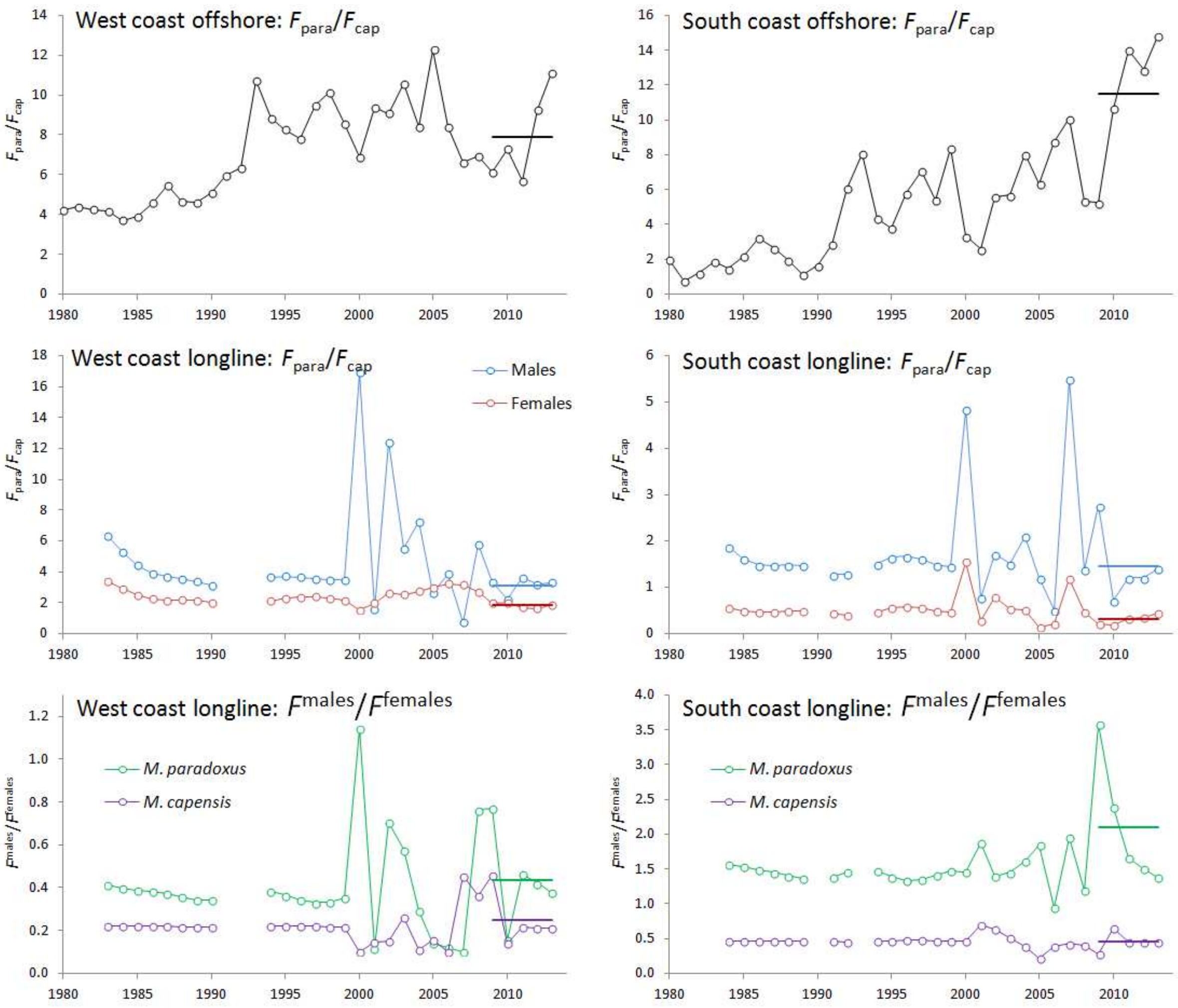

Figure 1: Trends in past F_{ratio} (F_{para}/F_{cap}) for the West and South Coast offshore trawl and longline fleet for the Reference Case assessment (RS1) within the Reference Set. For the longline fleet for which sex-disaggregated catches are available, the ratios are shown separately for males and females. The five-year averages over 2009-2013 are also shown.

APPENDIX A:

For reasons discussed in the main text, the code is structured to ensure that in any one year no more than 90% of any cohort can be taken by the fishery as a whole.

First to see whether this situation will arise under the standard equations for the dynamics for the TAC output by a CMP, for each species and age, check that:

$$\left[N_{ya}^{g} e^{-M_a^g/2} - \sum_f C_{fya}^{g}\right] \geq \left[0.1 N_{ya}^{g} e^{-M_a^g/2}\right] \tag{A1}$$

if $\left[N_{ya}^{g} e^{-M_a^g/2} - \sum_f C_{fya}^{g}\right] < \left[0.1 N_{ya}^{g} e^{-M_a^g/2}\right]$ for any age *a* then:

$$N_{y,a}^{*g} = N_{y^*a}^{g} e^{-M_a^g/2} \tag{A2}$$

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 A3 to A9:

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

$$F_{fy}^{'para} = 0.9 \tag{A3}$$

$$F_{fy}^{'cap} = \frac{C_{fy} - 0.9\sum_g \sum_{a=0}^{m} \tilde{w}_{fy,a+1/2}^{para,g} N_{ya}^{*para,g} S_{fya}^{para,g}}{\sum_g \sum_{a=0}^{m} \tilde{w}_{fy,a+1/2}^{cap,g} N_{ya}^{*cap,g} S_{fya}^{cap,g}} \tag{A4}$$

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

B] if $F_{fy}^{cap} > 0.9$ and $F_{fy}^{para} \leq 0.9$

$$F_{fy}^{'cap} = 0.9 \tag{A5}$$

$$F_{fy}^{'para} = \frac{C_{fy} - 0.9\sum_g \sum_{a=0}^{m} \tilde{w}_{fy,a+1/2}^{cap,g} N_{ya}^{*cap,g} S_{fya}^{cap,g}}{\sum_g \sum_{a=0}^{m} \tilde{w}_{fy,a+1/2}^{para,g} N_{ya}^{*para,g} S_{fya}^{para,g}} \tag{A6}$$

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

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

$$F_{fy}^{'para} = 0.9 \text{ and } F_{fy}^{'cap} = 0.9 \tag{A7}$$

$$C^{g}_{fya} = N^{*g}_{ya} F^{'}_{fy} S^{g}_{fya} \quad \text{(A8)}$$

$$N^{'g}_{y,a} = N^{*g}_{ya} - C^{g}_{fya} \quad \text{(A9)}$$

In equations A3, A5 and A7, $N^{*g}_{y,a}$ is replaced by $N^{'g}_{y,a}$.

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

$$N^{g}_{y+1,a+1} = N^{'g}_{ya} e^{-M^{g}_{a}/2} \qquad \text{for } 0 \leq a \leq m - 2 \quad \text{(A10)}$$

$$N^{g}_{y+1,m} = N^{'g}_{y,m-1} e^{-M^{g}_{m-1}/2} + N^{'g}_{y,m} e^{-M^{g}_{m}/2} \quad \text{(A11)}$$

Note: In the interests of simplicity, this process has avoided distinguishing the longline catches by gender, and works with gender-aggregated catches. However a flag has been inserted in the code to indicate whether this results in any gender-disaggregated number-at age going negative. Such instances will be dealt with in a case-specific manner should they arise.