The 2018 South Coast Rock Lobster Reference Case Operating Model

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SUMMARY

This document details the current 2018 Reference Case Operating Model which is to be proposed to be used for simulation testing of a new OMP for South Coast rock lobster.

DATA

Note the fishery is divided into three areas: Area 1E, Area 1W and Area 2+3 (for rationale see MARAM/IWS/2017/SCRL/BG1).

Catch

The historic annual catches for each area are provided by Glazer (2018a), who reports the catches from 1977[1]-2016. The TAC for the 2016 season was assumed to have been taken in full at the time of the 2018 assessment. The total catch for the resource is also known for the period 1973-1976. In order to split these total catches between the three areas for this early period, the average area catch-splits observed in the immediately following five-year period 1977-1981 were used. Table A1 (see Appendix A) reports the annual catches for each area.

CPUE

Standardised CPUE data for each area (for 1977-2016) are reported by Glazer (2018b). They are listed in Appendix A in Table A2.

[1] The convention used here is that the split season is referenced by the first year, e.g. 1977 refers to the 1977/78 season, where the season commences in October and ends the following September.

Scientific Catch-at-length data

Glazer (2013, 2015 and 2016) provides the scientific catch-at-length data for each area (in 5mm size-classes) for the period 1995-2015. The senior author subsequent adjusted some of these data to provide suitable plus- and minus-groups for input to fitting the population models. The rule applied was that an observed proportion of less than 1% should be incorporated into a plus or minus group. Tables A3a-f provide the final CAL input data as used in the assessments. Note that for each year, the male+female proportions will sum to 1.0 for each year.

The Age-Structured Production Model for the South Coast rock lobster

Introduction

The south coast rock lobster resource is modelled using an age-structured-production-model (ASPM) which fits to catch-at-length data directly. The model is sex-disaggregated (*m*/*f*) and area-disaggregated. Population equations have been modified from the Baranov form to Pope's approximation. This speeds the runtime of the program.

Note that the model estimates annual variability in the proportion of recruitment (age 0 lobsters) to each area each year. Though formally there is not inter-area movement allowed in the model after this recruitment, in effect this means that there is allowance for such movement, but only for ages less than those which the fishery exploits.

The model and fitting procedure described below take account of International Panel recommendations made at the November 2012 IWS (see Appendix B of this document).

1. The population model

The resource dynamics are modelled by the equations:

$$N^{m,A}_{y+1,0} = \lambda^A R_{y+1} \tag{1}$$

$$N^{f,A}_{y+1,0} = \lambda^A R_{y+1} \tag{2}$$

$$N^{m,A}_{y+1,a+1} = \sum_l [\vec{N}^{m,A}_{y,a,l} e^{-M^m/2} - \vec{C}^{m,A}_{y,a,l}] e^{-M^m/2} \qquad 0 \le a \le p-2 \tag{3}$$

$$N^{f,A}_{y+1,a+1} = \sum_l [\vec{N}^{f,A}_{y,a,l} e^{-M^f/2} - \vec{C}^{f,A}_{y,a,l}] e^{-M^f/2} \qquad 0 \le a \le p-2 \tag{4}$$

$$N^{m,A}_{y+1,p} = \sum_l [\vec{N}^{m,A}_{y,p-1,l} - \vec{C}^{m,A}_{y,p-1,l}] e^{-M^m/2} + \sum_l [\vec{N}^{m,A}_{y,p,l} - \vec{C}^{m,A}_{y,p,l}]\, e^{-M^m/2} \quad (5)$$

$$N^{f,A}_{y+1,p} = \sum_l [\vec{N}^{f,A}_{y,p-1,l} - \vec{C}^{f,A}_{y,p-1,l}] e^{-M^f/2} + \sum_l [\vec{N}^{f,A}_{y,p,l} - \vec{C}^{f,A}_{y,p,l}]\, e^{-M^f/2} \quad (6)$$

where

$N^{m/f,A}_{y,a}$ is the number of male or female (*m/f*) lobsters of age *a* at the start of year *y* in area *A*,

$\vec{N}^{m/f,A}_{y,a,l}$ is the number of male or female (*m/f*) lobsters of age *a* of length *l* at the start of year *y* in area *A* (see equation 23),

$M^{m/f}$ denotes the natural mortality rate for male or female (*m/f*) lobsters which is assumed to be constant for all ages *a* (and here identical for male and female lobsters); note that this value is fixed at *0.10* in this model,

$\vec{C}^{m/f,A}_{y,a,l}$ is the catch in numbers of male or female (*m/f*) lobsters of age *a* of length *l* in year *y* in area *A*, and

p is the maximum age considered (taken to be a plus-group).

Note: $\sum_A \lambda^A = 1$ and that $0 < \lambda^A < 1$. The model makes the assumption there is no cross-boundary movement after recruitment.

This assessment methodology has duplicated that of the primary assessment of 2013 but with one modification. Recall that for each Area *A*, the proportional split of recruitment, $\lambda^{*,A}_y$, is given by:

$$R^A_y = \lambda^{*,A}_y R_y \quad (7)$$

where

$$\lambda^{*,A}_y = \frac{\lambda^A e^{\varepsilon_{A,y}}}{\sum_A \lambda^A e^{\varepsilon_{A,y}}} \quad (8)$$

and

$$\varepsilon_{A,y} \sim N(0,\sigma_\lambda^2); \qquad \sigma_\lambda = 1.0$$

The $\lambda_y^{*,A}$ values from **1974** to **2008** are as estimated in the assessment.

The number of recruits of age 0, of each sex, at the start of year *y* is related to the spawner stock size by a stock-recruitment relationship:

$$R_y = \frac{\alpha B_y^{sp}}{\beta + B_y^{sp}} e^{\varsigma_y - \frac{\sigma_R^2}{2}} \qquad \varsigma_y \sim N(0,\sigma_R^2) \tag{9}$$

where σ_R =0.8,

α and β are spawner biomass-recruitment parameters, and

ς_y reflects fluctuation about the expected (median) recruitment for year *y*. These stock-recruit residuals are estimated for the period 1974-2008.

For 2009+

$$R_y = \frac{\alpha B_y^{sp}}{\beta + B_y^{sp}} e^{\varepsilon_y - \sigma_R^2/2} \qquad \varepsilon_y \sim N(0,\sigma_R^2) \tag{10}$$

B_y^{sp} is the spawner biomass at the start of year *y*, given by:

$$B_y^{sp} = \sum_{A=1}^{3}\sum_{a=1}^{p}\sum_{l=1}^{180} [f_l^A Q_{a,l}^{f,A} w_a^{f,A} N_{y,a}^{f,A}] \tag{11}$$

$$B_y^{sp} = \sum_{A=1}^{3}\sum_{a=1}^{p} N_{y,a}^{f,A} \sum_{l=1}^{180} [f_l^A Q_{a,l}^{f,A} w_a^{f,A}] \tag{12}$$

$$B_y^{sp} = \sum_{A=1}^{3}\sum_{a=1}^{p} N_{y,a}^{f,A} X_a^A \tag{13}$$

where

$$X_a^A = \sum_{l=1}^{180} f_l^A Q_{a,l}^{f,A} w_a^{f,A} \tag{14}$$

where $w_a^{f,A}$ is the begin-year mass of female lobsters at age *a* in area *A*, f_l^A is the proportion of lobsters of length l that are mature in area A, and, $Q_{a,l}^{m/f,A}$ is the proportion of lobsters of age *a* that fall in the length group *l* for the sex and area concerned (thus $\sum_l Q_{a,l}^{m/f,A} = 1$ for all ages *a*).

The matrix *Q* is calculated under the assumption that length-at-age is normally distributed about a mean given by the von Bertalanffy equation (Brandão *et al.*, 2002), i.e.:

$$l_a \sim N^*\left[l_\infty^{m/f,A}\left(1-e^{-\kappa(a-t_0)}\right);\theta_a^2\right] \tag{15}$$

where

*N** is the normal distribution truncated at ± 3 standard deviations, and

θ_a is the standard deviation of length-at-age *a*, which is modelled to be proportional to the expected length-at-age *a*, i.e.:

$$\theta_a = \beta^* l_\infty^{m/f,A}\left(1-e^{-\kappa(a-t_0)}\right) \tag{16}$$

with β^* a parameter estimated in the model fitting process.

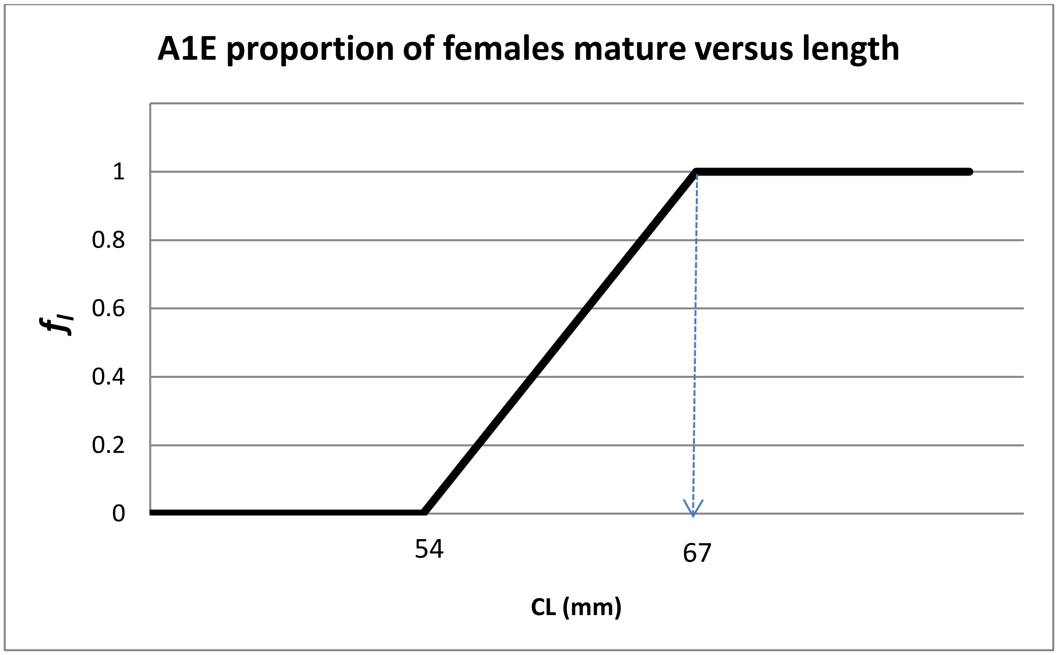
Estimating the proportion-mature at length for each area

Groeneveld and Melville-Smith produced estimates of the size at onset of sexual maturity of SCRL for three areas using two different methodologies (Groeneveld and Melville-Smith, 1994). These authors concluded that a gradient in the size at maturity occurred along the South Coast fishing grounds, with females in the more eastern areas attaining maturity at smaller sizes than those in more western areas. The three areas in this paper correspond well with the three areas which the SWG have identified for SCRL modelling i.e. A1E, A1W and A2+3. After examining the results presented in the Groeneveld and Melville-Smith paper, a task group concluded that a step-function for length-at-maturity vs length could be assumed using the value shown in the last column of Table 1. These correspond roughly to the *range* of lengths for which Groeneveld and Melveille-Smith found females to become mature.

Table 1: The sizes-at-50% maturity for the two different methodologies are as follows (Groeneveld and Melville-Smith 1994).

Sector studied in Groeneveld and Melville-Smith 1994	Corresponding SWG area	Mean size in CL (mm) at which 50% maturity is reported for the two methodologies	Range of sizes in CL (mm) over both methodologies for which females were found to be mature
Eastern	A1E	59, 62	54-68
Central	A1W	63, 71	58-77
Western	A2+3	65, 71	60-77

To develop a function of mature female lobsters versus length for each sub-area, i.e. f_l^A (the proportion mature at length in area A), the following is assumed. The method used for A1E is shown below.



Hence for A1E, one calculates f_l^{A1E} as follows:

$$f_l^{A1E} = 0 \quad \text{for } l < 54mm$$

$$f_l^{A1E} = \frac{1}{(67-54)} l + 1 - \frac{67}{67-54} \quad \text{for } 54mm \leq l < 68mm \tag{17}$$

$$f_l^{A1E} = 1 \quad \text{for } l \geq 68mm$$

Similar functions follow for the other two areas using the respective values shown in the final column of Table 1.

In order to work with estimable parameters that are more meaningful biologically, the stock-recruit relationship is re-parameterised in terms of the pre-exploitation equilibrium female spawning biomass, K^{sp}, and the "steepness" of the stock-recruit relationship (recruitment at $B^{sp} = 0.2K^{sp}$ as a fraction of recruitment at $B^{sp} = K^{sp}$):

$$\alpha = \frac{4hR_1}{5h-1} \tag{18}$$

and

$$\beta = \frac{(K^{sp}(1-h))}{5h-1} \tag{19}$$

where

$$R_1 = K^{sp} / \{\sum_A \lambda^A \, [\sum_{a=1}^{p-1} f_a e^{-\sum_{a'=0}^{a-1} M_{a'}^f} + f_p \frac{e^{\sum_{a'=0}^{p-1} M_{a'}^f}}{1-e^{-M_p^f}}]\} \tag{20}$$

and where the proportion mature at age $f_a^A = \sum_l f_l^A{}_l w_l^{f,A} Q_{a,l}^{f,A}$

It is assumed that the catch is taken mid-year so that the model first adjusts the numbers of lobsters by half the value of the annual natural mortality. The total catch by *mass* in year *y* for area *A* is then given by:

$$C_y^A = \sum_{m/f} \sum_a \sum_l w_{a+\frac{1}{2}}^{m/f,A} \vec{C}_{y,a,l}^{m/f,A} \tag{21}$$

where

$$\vec{C}_{y,a,l}^{m,A} = \vec{N}_{y,a,l}^{m,A} e^{-M^m/2} S_{y,l}^{m,A} F_y^A \tag{22}$$

$$\vec{C}_{y,a,l}^{f,A} = \vec{N}_{y,a,l}^{f,A} e^{-M^f} S_{y,l}^{f,A} F_y^A$$

where $w_l^{m/f,A}$ denotes the mass of a *m/f* lobster at length *l* in area *A*,

$S_{y,l}^{m/f,A}$ is the length-specific selectivity for male/female lobsters in area *A*, in year y,

F_y^A is the fully selected fishing mortality in year *y* for lobsters in area *A*, which is constrained to be $\leq$ 0.80, and

$$\vec{N}_{y,a,l}^{m/f,A} = N_{y,a}^{m/f,A} \ddot{Q}_{a,l}^{m/f,A} \tag{23}$$

where $\ddot{Q}_{a,l}^{m/f,A}$ is calculated using the von Bertalanffy equation (see equation 12), but the mid-year lengths at age are assumed, so that equation (12) is modified as follows:

$$l_a \sim N^*[l_\infty^{\frac{m}{f},A}\left(1-e^{-\kappa(a+0.5-t_0)}\right); \theta_a^2] \tag{24}$$

The model value for mid-year exploitable biomass (prior to fishing) is given by:

$$B_y^A = B_y^{m,A} + B_y^{f,A} \tag{25}$$

where

$$B_y^{f,A} = \sum_a \sum_l S_{y,l}^{f,A}[w_l^f \vec{N}_{y,a,l}^{f,A} e^{-M^f/2}] \tag{26}$$

$$B_y^{m,A} = \sum_a \sum_l S_{y,l}^{m,A}[w_l^m \vec{N}_{y,a,l}^{m,A} e^{-M^m/2}] \tag{27}$$

and where

B_y^A is the total (male plus female) model value for mid-year exploitable biomass for year *y* in area *A (prior to fishing)*.

The overall fishing proportion in area A is:

$$F_y^A = \frac{C_y^{obs,A}}{B_y^A} \tag{28}$$

Where $C_y^{obs,A}$ is the observed catch by weight of lobsters in year *y* in area *A*.

The final mid-year exploitable biomass that is used for model estimates of CPUE (see later section) then takes half the fishing mortality into account as follows:

$$B_y^A = B_y^{m,A} + B_y^{f,A} \tag{29}$$

where

$$B_y^{f,A} = \sum_a \sum_l S_{y,l}^{f,A}[w_l^f \vec{N}_{y,a,l}^{f,A} e^{-M^f/2}]\left[1.0 - (F_y^A S_{y,l}^{f,A})/2\right] \tag{30}$$

$$B_y^{m,A} = \sum_a \sum_l S_{y,l}^{m,A}[w_l^m \vec{N}_{y,a,l}^{m,A} e^{-M^m/2}]\left[1.0 - (F_y^A S_{y,l}^{m,A})/2\right] \tag{31}$$

Catch-at-length proportions

These are given by:

$$p_{y,l}^{m,A} = \frac{\sum_a \vec{C}_{y,a,l}^{m,A}}{\sum_l \sum_{m,f} \sum_a \vec{C}_{y,a,l}^{m/f,A}} \tag{32}$$

$$p_{y,l}^{f,A} = \frac{\sum_a \vec{C}_{y,a,l}^{f,A}}{\sum_l \sum_{m,f} \sum_a \vec{C}_{y,a,l}^{m/f,A}} \tag{33}$$

where $p_{y,l}^{m/f}$ is the estimated proportions of catch (by number) in area *A* of *m*/*f* lobsters in length class *l* in year *y* (note that the sum of the proportions of male plus female lobsters will consequently equal 1.0 for any given year and area).

Somatic Growth rate model

Growth is assumed to be both sex and area dependent. The κ (slope) parameter of the length increment versus length relationship is area-independent, but the intercepts vary by area. Thus the annual growth of a 75mm male lobster from each area is given by:

$$g75^{m,1E} = g75 + \Delta g1E + \Delta gm$$

$$g75^{m,1W} = g75 + \Delta g1W + \Delta gm$$

$$g75^{m,2+3} = g75 + \Delta gm$$

and the annual growth rate of a 75mm female lobster from each area is given by:

$$g75^{f,1E} = g75 + \Delta g1E$$

$$g75^{f,1W} = g75 + \Delta g1W$$

$$g75^{f,2+3} = g75.$$

[It follows that $l_{\infty}^{m/f,A} = 75.0 + (\frac{g75^{m/f,A}}{\kappa})$.]

Growth Model 8 of OLRAC (2012) is used, the values of the five associated somatic growth rate parameters are as reported in Table 2 below.

Table 2: The somatic growth-rate parameters.

	Estimates
g75	3.280 mm
κ	0.099 yr^{-1}
Δgm	0.996 mm
Δg1E	-2.840 mm
Δg1W	-0.790 mm

To put these parameter values into perspective, the values above result in l_∞ (mm) and g75 (mm) values as listed in Table 3 below.

Table 3: The resultant l_∞ (mm) and g75 values.

	l_∞ (mm)	g75 (mm)
A1Em	89.51	1.44
A1Ef	79.44	0.44
A1Wm	110.15	3.48
A1Wf	100.09	2.48
A2+3m	118.19	4.28
A2+3f	108.13	3.28

Selectivity-at-length function

The RC model assumes constant selectivity for areas A1E and A1W but time-varying selectivity for A2+3. The selectivity functions for males and females are:

$$S_{y,l}^{m,A} = \frac{e^{-\mu^{m,A}}}{1+e^{[-\delta^{m,A}(l-l_*^{m,A})]}} \quad (34)$$

$$S_{y,l}^{f,A} = \gamma^A \frac{e^{-\mu^{f,A}}}{1+e^{[-\delta^{f,A}(l-l_*^{f,A})]}} \quad (35)$$

Thus there are three estimable parameters for each sex and each area (μ, δ and l^*), and for each area a female scaling parameter γ^A.

For Area A2+3, selectivity is allowed to vary over time for the period for which there are catch-at-length data (1995-2015) by allowing time dependence in the μ, σ and l_* parameters.

Thus for Area A2+3, y=1995 to 2015:

$$l_*^m \rightarrow l_*^m + \varepsilon_{l*,y}^m \qquad \varepsilon_{l*,y}^m \sim N(0, \sigma_{l*,m}^2)$$

$$l_*^f \rightarrow l_*^f + \varepsilon_{l*,y}^f \qquad \varepsilon_{l*,y}^f \sim N(0, \sigma_{l*,f}^2)$$

$$\mu^m \rightarrow \mu^m + \varepsilon_{\mu,y}^m \qquad \varepsilon_{\mu,y}^m \sim N(0, \sigma_{\mu,m}^2)$$

$$\mu^f \rightarrow \mu^f + \varepsilon_{\mu,y}^f \qquad \varepsilon_{\mu,y}^f \sim N(0, \sigma_{\mu,f}^2)$$

$$\delta^m \rightarrow \delta^m + \varepsilon_{\delta,y}^m \qquad \varepsilon_{\delta,y}^m \sim N(0, \sigma_{\delta,m}^2)$$

$$\delta^f \rightarrow \delta^f + \varepsilon_{\delta,y}^f \qquad \varepsilon_{\delta,y}^f \sim N(0, \sigma_{\delta,f}^2)$$

An extra term is added to the negative log likelihood to limit the extent to which these time varying ε parameters may differ from zero – see equation 49.

An issue to be taken into account is that for equations (34) and (35), if $\delta_y^{m/f,A}$ decreases (as could eventuate for the time varying A2+3 selectivity functions), this means that selectivity is increasing on younger lobsters; however, given that the model fitting procedure assumes that:

$$CPUE = q \sum_l w_l S_{y,l} N_{y,l} e^{-M/2} \tag{36}$$

this situation seems implausible, as an enhanced CPUE would result even if there was not any increase in abundance.

Presumably enhanced catches of younger animals are achieved by spatially redistributing effort on a scale finer than captured by the GLM standardisation of the CPUE data. A standard method to adjust for this, while maintaining a constant catchability coefficient *q*, is to renormalise the selectivity function in some way:

$$S_{y,l}^{m/f,A} \rightarrow S_{y,l}^{*,m/f,A} = S_{y,l}^{m/f,A} / X_y^{m/f,A} \tag{37}$$

where here as a simple initial approach the following choice has been made:

$$X_y^{m/f,A} = \sum_{l_1^{m/f,A}}^{l_2^{m/f,A}} \frac{S_{y,l}^{m/f,A}}{l_2^{m/f,A} - l_1^{m/f,A} + 1} \tag{38}$$

i.e., selectivity is normailised by its average over a certain length range, so that now if $\delta_y^{m/f,A}$ decreases, the $S_{y,l}^{*,m/f,A}$ will decrease for large *l* to compensate for the effort spread to locations where younger animals are found which is assumed to be the reason for the increase for smaller *l*.

The values of $l_1^{m/f,A}$ and $l_2^{m/f,A}$ were fixed at the values shown in Table 4 to ensure that the ranges associated with these *l* values cover the greater part of these distributions.

Table 4: The values of $l_1^{m/f,A}$ and $l_2^{m/f,A}$ used in the OM tuning.

	$l_1^{m/f,A}$	$l_2^{m/f,A}$
A1E male	65	90
A1E female	65	90
A1W male	65	90
A1W female	65	90
A2+3 male	55	90
A2+3 female	55	90

Time varying recruitment distribution over areas

The model is further expanded to allow for recruitment distributions which vary over time for each of the three areas, as follows.

Without time-varying recruitment:

$$R_y^A = \lambda^A R_y \qquad \text{(see equation (1))}$$

With time variation this becomes:

$$R_y^A = \lambda_y^{*,A} R_y \tag{39}$$

where

$$\lambda_y^{*,A} = \frac{\lambda^A e^{\varepsilon_{A,y}}}{\sum_A \lambda^A e^{\varepsilon_{A,y}}} \tag{40}$$

The $\varepsilon_{A,y}$ are thus further estimable parameters. A further additional term is added to the –ln*L* function (see equation 48 below) to limit the size of these variations.

2. The (penalised) likelihood function

The model is fitted to CPUE and catch-at-length (male and female separately) data from each of the three areas to estimate the model parameters. Contributions by each of these to the negative log-likelihood (-ln*L*), and the various additional penalties added, are as follows.

Relative abundance data (CPUE)

The likelihood is calculated assuming that the abundance index observed is log-normally distributed about its expected (median) value:

$$CPUE_y^A = q^A B_y^A e^{\varepsilon_y^A} \text{ or } \varepsilon_y^A = \ln(CPUE_y^A) - \ln(q^A B_y^A) \tag{41}$$

where

$CPUE_y^A$ is the CPUE abundance index for year *y* in area *A*,

B_y^A is the model value for of mid-year exploitable biomass for year *y* in area *A* given by equation 29,

q^A is the constant of proportionality (catchability coefficient) for area *A*, and

ε_y^A is from $N(0,(\sigma^A)^2)$.

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

$$-\ln L = \sum_A \sum_y \left[\left(\varepsilon_y^A\right)^2 / 2(\sigma^A)^2 + \ln(\sigma^A) \right] \tag{42}$$

where

σ^A is the residual standard deviation estimated in the fitting procedure by its maximum likelihood value:

$$\hat{\sigma}^A = \sqrt{1/n\sum_y \left(\ln CPUE_y^A - \ln \hat{q}^A \hat{B}_y^A\right)^2} \quad (43)$$

where

n is the number of data points in the CPUE series, and

q^A is the catchability coefficient, estimated by its maximum likelihood value:

$$\ln \hat{q}^A = 1/n\sum_y \left(\ln CPUE_y^A - \ln \hat{B}_y^A\right) \quad (44)$$

Catches-at-length

The following term is added to the negative log-likelihood:

$$-ln\,L^{length} = w_{len}\sum_A\sum_y\sum_l\sum_{m/f}[\ln\left(\frac{\sigma_{len}^A}{\sqrt{p_{y,l}^{\frac{m}{f},A}}}\right) + p_{y,l}^{m/f,A}\left(\ln \quad p_{y,l}^{m/f,A} - \ln \hat{p}_{y,l}^{m/f,A}\right)^2/2(\sigma_{len}^A)^2] \quad (45)$$

where

$p_{y,l}^{m/f,A}$ is the observed proportion of *m/f* lobsters (by number) in length group *l* in the catch in year *y* in area *A*, and

σ_{len}^A is the standard deviation associated with the length-at-age data in area *A*, which is estimated in the fitting procedure as:

$$\hat{\sigma}_{len}^A = \sqrt{\sum_{m/f}\sum_y\sum_l p_{y,l}^{m/f,A}\left(\ln p_{y,l}^{m/f,A} - \ln \hat{p}_{y,l}^{m/f,A}\right)^2 / \sum_{m/f}\sum_y\sum_l 1} \quad (46)$$

Equation (45) makes the assumption that proportion-at-length data are log-normally distributed about their model-predicted values. The associated variance is taken to be inversely proportional to $p_{y,l}^{m/f,A}$ to down-weight contributions from observed small proportions which will correspond to small predicted sample sizes.

The reference case (RC) model fixes w_{len} = 1.0 (i.e. gives equal weight to the CAL data as to the CPUE data).

Stock-recruitment function residuals

The assumption that these residuals are log-normally distributed and could be serially correlated defines a corresponding joint prior distribution. This can be equivalently regarded as a penalty function added to the log-likelihood, which for fixed serial correlation ρ is given by:

$$-\ln L = -\ln L + \sum_{y=y1}^{y2}\left[\frac{\varsigma_y - \rho\varsigma_{y-1}}{\sqrt{1-\rho^2}}\right]^2 / 2\sigma_R^2 \qquad (47)$$

where

$\varsigma_y = \rho\tau_{y-1} + \sqrt{1-\rho^2}\eta_y$ is the recruitment residual for year *y*, which is estimated for years *y1* to *y2* if $\rho = 0$, or *y1*+1 to *y2* if $\rho > 0$,

$\eta_y \sim N(0,\sigma_R^2)$,

σ_R is the standard deviation of the log-residuals, which is input, and

ρ is their serial correlation coefficient, which is input.

Note that here (as in previous assessments), ρ is set equal to zero, i.e. the recruitment residuals are assumed uncorrelated, and σ_R is set equal to 0.8. Because of the absence of informative length data for a longer period, recruitment residuals are estimated for years 1974 to 2008 only.

Time varying recruitment distribution parameters

The following term is added to the –ln*L* term to constrain the size of these terms in equation 33 (i.e. to fit to genuine differences rather than to noise):

$$-\ln L = -\ln L + \sum_A \sum_{y=1974}^{y=2008} \left(\frac{\varepsilon_{A,y}^2}{\sigma_\lambda^2}\right) \qquad (48)$$

where σ_λ=1.0.

Time varying selectivity

An extra term is added to the likelihood function in order to smooth the extent of change in the selectivity for A2+3, as follows:

$$-lnL \rightarrow -lnL + \frac{1}{2}\sum_{y,m/f}\left(\frac{\varepsilon^{m}_{l*,y}}{\sigma_{l*,m}}\right)^2 + \left(\frac{\varepsilon^{f}_{l*,y}}{\sigma_{l*,f}}\right)^2 + \left(\frac{\varepsilon^{m}_{\mu,y}}{\sigma_{\mu,m}}\right)^2 + \left(\frac{\varepsilon^{f}_{\mu,y}}{\sigma_{\mu,f}}\right)^2 + \left(\frac{\varepsilon^{m}_{\delta,y}}{\sigma_{\delta,m}}\right)^2 + \left(\frac{\varepsilon^{f}_{\delta,y}}{\sigma_{\delta,f}}\right)^2 \qquad (49)$$

where the σ values are input as follows:

$\sigma_{l*,m/f}$ = 3.0

$\sigma_{\mu,m/f}$ = 0.01

$\sigma_{\delta,m/f}$ 0.10.

Somatic growth parameters – within model estimation

The somatic growth rate parameters are updated in the model fitting process.

The growth parameters constitute a vector **x.** The following contribution is then added to the penalised negative log-likelihood in the assessment:

$$-\ln L^{c} = \frac{1}{2}\ln|\mathbf{\Sigma}| + \frac{1}{2}(\mathbf{x}-\boldsymbol{\mu})^{\mathrm{T}}\mathbf{\Sigma}^{-1}(\mathbf{x}-\boldsymbol{\mu}) \qquad (50)$$

where the parameters *g75,* $\kappa, \Delta gm, \Delta g1E\ and\ \Delta g1w$ are components of the vector ***x,***

$\mathbf{\Sigma}$ is the variance covariance matrix (as provided by OLRAC (2012)), and

$\boldsymbol{\mu}$ is a vector which contains the estimates (as provided by OLRAC (2012)).

3. Model parameter values fixed prior to model fitting

Natural mortality: Natural mortality $M^{m/f}$ for male and female lobsters is assumed to be the same (*M*) for all age classes and both sexes, and is fixed at 0.10 yr^{-1}.

Minimum age: a = 0.

Maximum age: *p* = 20, and is taken to be a plus-group.

Minimum length: length 1mm.

Maximum length: 180mm, which is taken to be a plus-group.

Mass-at-age at start of year: The mass $w_a^{m/f,A}$ of a *m/f* lobster at age *a* in area *A* is given by:

$$w_a^{m/f,A} = \alpha\left[\hat{L}_\infty^{m/f,A}\left(1-e^{-\hat{\kappa}\left(a-\hat{t}_0\right)}\right)\right]^\beta \quad (51)$$

Mass-at-length:

$$w_l^{m/f,A} = \alpha l^\beta \quad (52)$$

where the values of α and β are 0.0007 and 2.846 (units in terms of gm and mm) respectively (and are assumed constant for male and female lobsters and across areas).

Estimable parameters of the RC

Table 4: Estimable parameters of the Reference Case assessment model. (TVS=Time Varying Selectivity).

Parameter	What is it	Number of parameters
K^{sp}	Pristine female spawning biomass	1
h	Steepness parameter of SR function	1
β^{*}	Parameter of length-at-age distribution	1
$\mu^{m/f,A}$	Selectivity function parameter	6
$l_{*}^{m/f,A}$	Selectivity function parameter	6
$\delta^{m/f,A}$	Selectivity function parameter	6
γ^{A}	Relative female selectivity scaling parameters	3
$\varepsilon_{l*,y}^{m}$	TVS for A2+3	21
$\varepsilon_{l*,y}^{f}\sim$	TVS for A2+3	21
$\varepsilon_{\mu,y}^{m}\sim$	TVS for A2+3	21
$\varepsilon_{\mu,y}^{f}$	TVS for A2+3	21
$\varepsilon_{\delta,y}^{m}$	TVS for A2+3	21
$\varepsilon_{\delta,y}^{f}\sim$	TVS for A2+3	21
λ^{A}	Area specific recruitment proportion	3
$\varepsilon_{A,y}$	Time varying recruitment distribution	72
ς_{y}	Stock recruit residuals	35
g75	Somatic growth parameter	1
κ	Somatic growth parameter	1
Δgm	Somatic growth parameter	1
Δg1E	Somatic growth parameter	1
Δg1W	Somatic growth parameter	1
TOTAL		**262**

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Appendix A: List of data used in fitting the 2018 SCRL ASPM

Table A1: Historic annual catch (MT) from each of the three areas (from Glazer 2018a). The average area catch splits for the period 1977-1981 are used to produce the catches for 1973-76.

Year	Area 1E	Area 1W	Area 2+3
1973			
1974	No data avaiable in the catch-		
1975	effort database for these years		
1976			
1977	69.73	175.95	421.32
1978	4.21	97.82	358.97
1979	0.37	31.52	90.11
1980	25.41	86.06	64.54
1981	15.27	122.99	209.74
1982	57.84	88.45	260.71
1983	12.20	112.95	398.84
1984	45.23	155.77	248.99
1985	1.05	84.47	364.48
1986	6.84	103.82	339.34
1987	3.73	102.50	345.77
1988	11.44	88.38	352.19
1989	49.86	62.50	339.64
1990	38.18	191.94	246.87
1991	60.85	122.21	341.48
1992	38.65	108.02	383.29
1993	43.68	147.54	333.05
1994	42.76	176.44	288.69
1995	34.93	87.75	382.21
1996	68.27	63.91	310.50
1997	31.06	74.51	310.82
1998	31.94	161.26	322.83
1999	56.65	191.98	263.54
2000	123.26	86.96	213.18
2001	18.92	89.61	179.47
2002	11.56	199.01	129.43
2003	18.55	188.63	142.82
2004	23.61	143.41	214.99
2005	21.58	152.09	208.33
2006	145.85	52.18	182.98
2007	93.96	79.47	213.57
2008	46.33	85.75	232.92
2009	61.22	123.44	160.35
2010	117.39	157.96	52.65
2011	62.98	126.75	117.27
2012	29.78	88.13	177.10
2013	6.28	62.58	275.14
2014	1.94	90.24	237.82
2015	38.98	163.38	98.64
2016	31.76	157.42	113.81

Table A2: Standardised CPUE indices (kg/trap) for each area (from Glazer 2018b).

Year	Area 1E	Area 1W	Area 2+3
1977	2.51	1.85	2.20
1978	1.40	1.45	1.98
1979	1.05	1.55	1.75
1980	2.73	2.21	1.99
1981	2.44	1.75	1.88
1982	1.93	1.54	1.58
1983	1.61	1.75	1.82
1984	2.25	1.60	1.68
1985	0.44	1.40	1.58
1986	1.20	1.59	1.91
1987	0.99	2.04	1.72
1988	1.74	2.05	2.02
1989	3.23	1.87	2.02
1990	1.84	1.82	1.57
1991	1.41	1.34	1.40
1992	1.93	1.14	1.51
1993	1.39	1.03	1.35
1994	0.99	1.08	1.15
1995	1.24	0.90	1.14
1996	0.97	0.90	0.94
1997	0.89	0.89	0.83
1998	1.50	1.26	0.68
1999	1.22	1.01	0.67
2000	1.66	1.05	0.73
2001	1.48	1.32	0.87
2002	1.72	1.45	0.79
2003	1.68	1.37	0.98
2004	1.91	1.29	1.36
2005	1.37	1.21	1.04
2006	1.30	0.78	0.82
2007	1.07	1.09	1.10
2008	1.39	1.22	1.15
2009	1.15	1.18	0.85
2010	1.33	1.23	0.93
2011	0.94	1.09	0.94
2012	0.83	0.89	0.96
2013	1.37	1.28	1.40
2014	1.41	1.41	1.27
2015	1.97	1.47	1.03
2016	1.62	1.21	0.96

Table 3a: Area 1E male scientific catch-at-length proportions. Note “45” refers to the 45-49 mm carapace length range. Values bolded are those that were adjusted from the raw format to prevent proportions which are less than 0.01.

	1995	**1996**	**1997**	**1998**	**1999**	**2000**	**2001**	**2002**	**2003**	**2004**	**2005**	**2006**	**2007**	**2008**	**2009**	**2010**	**2011**	**2012**	**2013**	**2014**	**2015**
45	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
50	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.006
55	0.000	0.000	0.030	0.000	0.017	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.013	0.000	0.000	0.000	0.037	0.053	0.000	0.009
60	0.000	0.026	0.106	0.000	0.081	0.015	0.044	0.000	0.000	0.000	0.000	0.000	0.035	0.072	0.014	0.052	0.107	0.026	0.036	0.000	0.008
65	0.000	0.072	0.178	0.000	0.134	0.103	0.127	0.035	0.000	0.040	0.000	0.000	0.082	0.121	0.078	0.245	0.191	0.128	0.141	0.000	0.006
70	0.000	0.105	0.173	0.000	0.105	0.176	0.166	0.189	0.000	0.242	0.000	0.000	0.108	0.135	0.182	0.171	0.108	0.179	0.180	0.000	0.022
75	0.000	0.056	0.086	0.000	0.053	0.104	0.084	0.247	0.000	0.294	0.000	0.000	0.088	0.102	0.144	0.064	0.087	0.154	0.121	0.000	0.107
80	0.000	0.015	0.000	0.000	0.023	0.034	0.036	0.156	0.000	0.125	0.000	0.000	0.085	0.065	0.063	0.028	0.066	0.096	0.081	0.000	0.127
85	0.000	0.000	0.000	0.000	0.011	0.000	0.014	0.050	0.000	0.026	0.000	0.000	0.046	0.033	0.022	0.015	0.034	0.025	0.027	0.000	0.075
90	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.013	0.000	0.000	0.000	0.000	0.018	0.023	0.011	0.000	0.027	0.017	0.019	0.000	0.015
95	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.006
100	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.002
105	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.002
110	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
115	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
120	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
125	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000

Table 3b: Area 1E female scientific catch-at-length proportions. Note “45” refers to the 45-49 mm carapace length range. Values bolded are those that were adjusted from the raw format to prevent proportions which are less than 0.01.

	1995	**1996**	**1997**	**1998**	**1999**	**2000**	**2001**	**2002**	**2003**	**2004**	**2005**	**2006**	**2007**	**2008**	**2009**	**2010**	**2011**	**2012**	**2013**	**2014**	**2015**
45	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
50	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.003
55	0.000	0.021	0.047	0.000	0.049	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.016	0.000	0.000	0.000	0.000	0.014	0.000	0.011
60	0.000	0.119	0.101	0.000	0.147	0.047	0.092	0.000	0.000	0.000	0.000	0.000	0.055	0.054	0.022	0.042	0.095	0.026	0.038	0.000	0.005
65	0.000	0.289	0.138	0.000	0.187	0.206	0.189	0.066	0.000	0.071	0.000	0.000	0.129	0.102	0.112	0.216	0.150	0.077	0.117	0.000	0.030
70	0.000	0.239	0.104	0.000	0.124	0.212	0.167	0.112	0.000	0.118	0.000	0.000	0.165	0.098	0.175	0.119	0.059	0.095	0.088	0.000	0.099
75	0.000	0.058	0.069	0.000	0.051	0.086	0.066	0.081	0.000	0.069	0.000	0.000	0.118	0.082	0.114	0.032	0.027	0.071	0.044	0.000	0.245
80	0.000	0.000	0.000	0.000	0.019	0.015	0.015	0.037	0.000	0.016	0.000	0.000	0.049	0.049	0.041	0.017	0.030	0.047	0.041	0.000	0.180
85	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.013	0.000	0.000	0.000	0.000	0.021	0.024	0.023	0.000	0.020	0.021	0.000	0.000	0.036
90	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.012	0.000	0.000	0.000	0.000	0.000	0.000	0.003
95	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.003
100	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
105	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
110	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
115	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
120	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
125	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000

Table 3c: Area 1W male scientific catch-at-length proportions. Note “45” refers to the 45-49 mm carapace length range. Values bolded are those that were adjusted from the raw format to prevent proportions which are less than 0.01.

	1995	**1996**	**1997**	**1998**	**1999**	**2000**	**2001**	**2002**	**2003**	**2004**	**2005**	**2006**	**2007**	**2008**	**2009**	**2010**	**2011**	**2012**	**2013**	**2014**	**2015**
45	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
50	0.000	0.019	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
55	0.000	0.023	0.000	0.000	0.012	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
60	0.018	0.027	0.032	0.023	0.043	0.000	0.011	0.000	0.000	0.000	0.025	0.014	0.031	0.078	0.037	0.025	0.044	0.015	0.015	0.003	0.004
65	0.069	0.051	0.049	0.073	0.079	0.019	0.056	0.027	0.042	0.035	0.028	0.126	0.076	0.110	0.149	0.081	0.076	0.057	0.047	0.009	0.009
70	0.130	0.084	0.095	0.109	0.095	0.085	0.150	0.080	0.110	0.076	0.050	0.231	0.123	0.138	0.151	0.158	0.085	0.114	0.056	0.063	0.048
75	0.099	0.087	0.128	0.106	0.083	0.143	0.163	0.125	0.155	0.100	0.082	0.196	0.111	0.114	0.117	0.134	0.084	0.127	0.104	0.056	0.072
80	0.061	0.067	0.090	0.084	0.063	0.127	0.095	0.118	0.142	0.105	0.109	0.208	0.081	0.080	0.067	0.105	0.092	0.118	0.102	0.102	0.090
85	0.040	0.045	0.049	0.051	0.048	0.084	0.044	0.088	0.089	0.083	0.092	0.092	0.051	0.056	0.036	0.044	0.061	0.071	0.106	0.107	0.100
90	0.033	0.027	0.028	0.030	0.039	0.058	0.021	0.051	0.051	0.056	0.065	0.036	0.024	0.032	0.022	0.034	0.048	0.059	0.107	0.096	0.088
95	0.026	0.016	0.019	0.019	0.023	0.031	0.010	0.028	0.022	0.031	0.025	0.000	0.018	0.021	0.000	0.016	0.021	0.016	0.034	0.102	0.096
100	0.023	0.010	0.020	0.015	0.021	0.018	0.011	0.019	0.014	0.021	0.013	0.000	0.000	0.000	0.000	0.015	0.023	0.000	0.023	0.029	0.037
105	0.000	0.000	0.000	0.018	0.000	0.016	0.000	0.000	0.000	0.019	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.018	0.029
110	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.002	0.002
115	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.001	0.001
120	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
125	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000

Table 3d: Area 1W female scientific catch-at-length proportions. Note “45” refers to the 45-49 mm carapace length range. Values bolded are those that were adjusted from the raw format to prevent proportions which are less than 0.01.

	1995	**1996**	**1997**	**1998**	**1999**	**2000**	**2001**	**2002**	**2003**	**2004**	**2005**	**2006**	**2007**	**2008**	**2009**	**2010**	**2011**	**2012**	**2013**	**2014**	**2015**
45	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
50	0.000	0.024	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
55	0.000	0.024	0.012	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.013	0.000	0.000	0.000	0.000	0.000	0.000	0.001
60	0.033	0.034	0.035	0.040	0.050	0.000	0.018	0.000	0.000	0.000	0.028	0.000	0.047	0.055	0.034	0.017	0.039	0.012	0.011	0.001	0.001
65	0.102	0.085	0.068	0.097	0.096	0.031	0.074	0.038	0.033	0.039	0.048	0.000	0.087	0.081	0.113	0.068	0.080	0.064	0.043	0.006	0.006
70	0.133	0.130	0.127	0.118	0.112	0.090	0.153	0.093	0.086	0.091	0.085	0.000	0.118	0.075	0.116	0.098	0.090	0.107	0.057	0.062	0.043
75	0.086	0.111	0.121	0.096	0.102	0.115	0.116	0.129	0.109	0.106	0.119	0.000	0.098	0.060	0.089	0.069	0.076	0.095	0.080	0.065	0.068
80	0.060	0.069	0.070	0.062	0.081	0.092	0.045	0.093	0.081	0.097	0.107	0.000	0.068	0.041	0.045	0.067	0.072	0.075	0.080	0.094	0.072
85	0.044	0.038	0.033	0.035	0.032	0.051	0.021	0.057	0.037	0.062	0.069	0.000	0.041	0.027	0.027	0.026	0.036	0.036	0.053	0.073	0.069
90	0.023	0.026	0.016	0.025	0.008	0.025	0.013	0.033	0.025	0.040	0.033	0.022	0.025	0.020	0.000	0.023	0.035	0.035	0.053	0.050	0.057
95	0.011	0.000	0.011	0.000	0.015	0.016	0.000	0.020	0.000	0.021	0.022	0.043	0.000	0.000	0.000	0.020	0.014	0.000	0.018	0.040	0.060
100	0.009	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.018	0.000	0.022	0.000	0.000	0.000	0.000	0.024	0.000	0.011	0.013	0.028
105	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.010	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.006	0.015
110	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
115	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
120	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
125	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000

Table 3e: Area 2+3 male scientific catch-at-length proportions. Note “45” refers to the 45-49 mm carapace length range. Values bolded are those that were adjusted from the raw format to prevent proportions which are less than 0.01.

	1995	**1996**	**1997**	**1998**	**1999**	**2000**	**2001**	**2002**	**2003**	**2004**	**2005**	**2006**	**2007**	**2008**	**2009**	**2010**	**2011**	**2012**	**2013**	**2014**	**2015**
45	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
50	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.001	0.000
55	0.016	0.000	0.000	0.028	0.020	0.010	0.000	0.016	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.027	0.004	0.001
60	0.095	0.059	0.067	0.063	0.116	0.054	0.014	0.046	0.030	0.040	0.024	0.000	0.075	0.069	0.046	0.000	0.033	0.034	0.037	0.012	0.009
65	0.138	0.082	0.132	0.090	0.186	0.103	0.047	0.063	0.045	0.049	0.060	0.074	0.128	0.109	0.098	0.055	0.062	0.051	0.052	0.025	0.022
70	0.083	0.068	0.089	0.078	0.111	0.095	0.099	0.078	0.081	0.071	0.107	0.152	0.124	0.087	0.119	0.133	0.147	0.071	0.088	0.048	0.039
75	0.046	0.055	0.051	0.044	0.031	0.065	0.102	0.082	0.107	0.077	0.097	0.166	0.066	0.050	0.101	0.103	0.095	0.066	0.083	0.084	0.064
80	0.042	0.056	0.043	0.042	0.015	0.049	0.088	0.066	0.092	0.077	0.076	0.165	0.052	0.037	0.064	0.145	0.107	0.072	0.094	0.081	0.071
85	0.034	0.049	0.033	0.039	0.015	0.041	0.061	0.049	0.055	0.053	0.057	0.083	0.039	0.033	0.036	0.030	0.036	0.047	0.057	0.073	0.071
90	0.023	0.035	0.026	0.037	0.012	0.034	0.039	0.034	0.035	0.041	0.036	0.037	0.026	0.036	0.022	0.036	0.032	0.056	0.052	0.059	0.054
95	0.017	0.025	0.020	0.026	0.011	0.022	0.023	0.021	0.019	0.023	0.023	0.019	0.022	0.032	0.012	0.032	0.014	0.033	0.024	0.051	0.054
100	0.011	0.020	0.017	0.018	0.000	0.015	0.012	0.014	0.012	0.023	0.014	0.017	0.019	0.027	0.011	0.015	0.015	0.039	0.017	0.030	0.035
105	0.016	0.017	0.022	0.018	0.000	0.021	0.013	0.015	0.014	0.000	0.015	0.000	0.012	0.025	0.000	0.000	0.000	0.019	0.014	0.028	0.029
110	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.011	0.000	0.000	0.000	0.000	0.017	0.000	0.012	0.014
115	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.007	0.004
120	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.003	0.002
125	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.003	0.000

Table 3f: Area 2+3 male scientific catch-at-length proportions. Note “45” refers to the 45-49 mm carapace length range. Values bolded are those that were adjusted from the raw format to prevent proportions which are less than 0.01.

	1995	**1996**	**1997**	**1998**	**1999**	**2000**	**2001**	**2002**	**2003**	**2004**	**2005**	**2006**	**2007**	**2008**	**2009**	**2010**	**2011**	**2012**	**2013**	**2014**	**2015**
45	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
50	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.002	0.000
55	0.026	0.019	0.013	0.034	0.054	0.020	0.000	0.021	0.000	0.010	0.000	0.000	0.011	0.017	0.000	0.000	0.000	0.000	0.000	0.005	0.002
60	0.126	0.065	0.085	0.065	0.168	0.075	0.022	0.050	0.034	0.035	0.034	0.000	0.073	0.059	0.046	0.000	0.031	0.033	0.022	0.008	0.014
65	0.127	0.096	0.112	0.085	0.135	0.099	0.071	0.066	0.061	0.055	0.075	0.016	0.094	0.092	0.089	0.040	0.060	0.044	0.032	0.023	0.021
70	0.062	0.089	0.074	0.067	0.052	0.070	0.112	0.087	0.117	0.091	0.111	0.019	0.058	0.073	0.104	0.104	0.132	0.073	0.076	0.033	0.055
75	0.042	0.074	0.052	0.064	0.022	0.055	0.107	0.090	0.120	0.109	0.103	0.022	0.038	0.053	0.087	0.083	0.073	0.068	0.079	0.068	0.066
80	0.030	0.063	0.048	0.069	0.018	0.055	0.083	0.073	0.082	0.101	0.065	0.049	0.037	0.045	0.062	0.120	0.087	0.072	0.093	0.067	0.081
85	0.027	0.051	0.041	0.051	0.015	0.041	0.051	0.052	0.044	0.066	0.041	0.047	0.034	0.044	0.043	0.025	0.027	0.048	0.056	0.079	0.072
90	0.020	0.036	0.035	0.039	0.019	0.032	0.029	0.036	0.026	0.042	0.031	0.062	0.033	0.048	0.028	0.034	0.028	0.057	0.048	0.061	0.056
95	0.009	0.020	0.020	0.022	0.000	0.021	0.015	0.020	0.015	0.022	0.017	0.052	0.026	0.037	0.017	0.030	0.021	0.038	0.025	0.050	0.055
100	0.011	0.022	0.010	0.020	0.000	0.012	0.013	0.020	0.013	0.014	0.013	0.019	0.023	0.010	0.013	0.015	0.000	0.034	0.015	0.029	0.045
105	0.000	0.000	0.010	0.000	0.000	0.011	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.014	0.012	0.027	0.038
110	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.013	0.000	0.014	0.017
115	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.008	0.007
120	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.006	0.002
125	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.001	0.000

Appendix B: International Panel recommendations made at the November 2012 IWS

A. South Coast rock lobster

A.1 (H) Review how the catch size-composition data are constructed for each area/quarter. Impose a minimum on the number of animals which are measured during each sampling event (~50) and on the number of samples which are needed for inclusion in the assessment. [Review assessment; Is there a need for time-varying selectivity; how best is this modelled?; See A.6 below for how this information could be used to inform the design of the observer program.]

A.2 (H) Examine whether the size-frequencies differ among quarters, for example by applying a GLM to the mean catch lengths and to their standard deviations, including quarter as a factor. If there are consistent differences among quarters, this may impact how catch length-frequencies need to be constructed. [Review assessment; Is there a need for time-varying selectivity; how best is this modelled? See A.6 below for how this information could be used to inform the design of the observer program.]

A.3 (H) Further investigate the way time-varying selectivity is modelled. Variant 2, developed during the workshop, which allows for time-varying selectivity only for areas 2 and 3 led to a fit to the data which was not significantly worse than a model which allows for time-varying selectivity in all areas. Models with no time-varying selectivity, and models in which the values for δ for females are constant proportions of those for males, should be explored. The selection of a base-case formulation for time-varying selectivity should be decided considering the ability to fit the data, and the sensitivity of model results to the weight assigned to the size-composition data (wlen). [Review assessment; Is there a need for time-varying selectivity; how best is this modelled?]

A.4 (H) Some analyses of the tagging data suggest that total mortality may differ between areas 2 and 3. Consequently, the sensitivity tests should include operating models that distinguish these two areas (model 2 in MARAM IWS/NOV12/SCRL/P2). [Review assessment.]

A.5 (H) When evaluating candidate OMPs, construct sensitivity tests based on the following specifications:

(a) model the parameter δ, which determines time-varying-selectivity, as an AR-1 processes in time;

(b) weight the size-frequencies for each year as a function of sample size (perhaps with the weight increasing linearly from 0 at zero sample size to 1 at some intermediate sample size);

(c) examine different assumptions regarding spatial structure (models 2 and 3 of MARAM IWS/NOV12/SCRL/P2);

(d) change the value of the parameter (wlen) which weights the length-frequency data;

(e) change the value assumed for natural mortality, M (e.g. to 0.08 and 0.15yr-1);

(f) estimate separate residual variance parameters for the trawl CPUE series for the years before and after 1990 in area 1E (given the apparent reduction in inter-annual variation in CPUE after 1990; Figure 1a of MARAM/IWS/NOV12/REP/1 4 IWS/NOV12/SCRL/P2);

(g) set steepness to 0.8;

(h) consider alternative models for time-varying selectivity (e.g. no time-varying selectivity at all; no time-varying selectivity for areas 1E and 1W; perfect correlation between δ for males and females);

(i) change the values for σλ, σsel, σR and ρ; and

(j) consider alternative scenarios for the historical catches. Show results for cases in which catchability for the commercial fishery is changing over time. These latter sensitivity tests would not be used to select an OMP, but would rather be used to understand the behaviour of the OMP, given a factor which should substantially impact performance. [Provide advice on range of operating models for OMP testing.]

A.6 (M) The outcomes of recommendations A1 and A2 should be used to refine the design of the observer program. Therefore, the results of the analyses which explore the ideal number of samples per quarter, number of animals per sample, and the distribution of samples among quarters and areas should be provided to the group considering modifications to observer program. Consider how the size of the catch (e.g., over the most-recent five years) impacts the amount of size-composition data needed.

A.7 (M) Reparameterize the way in which the year-specific recruitment proportions by areas (A,y in equation A.29 in MAMARM IWS/NOV12/SCRL/P2) are modelled, so that one of the areas acts as a reference and the estimated parameters define deviations for the other areas with respect to the reference. [Review assessment.]

A.8 (M) Reparameterize the way in which the average recruitment proportions to areas (λ A, in equation A.29 in MAMARM IWS/NOV12/SCRL/P2) are modelled to avoid calculating the proportion for area 3 by subtracting those for areas 1 and 2 from unity. This can be achieved by setting λ for area 1E to 1, estimating λ for areas 1W and 2+3, and renormalizing by dividing by the sum of the 3 λ's. [Review assessment.]

A.9 (M) Compare the estimates of total mortality from the assessment with the corresponding estimates based on the tagging data (MARAM IWS/NOV12/SCRL/BG5) to confirm earlier results that the tagging data and the model outputs are comparable. [Review assessment.]

A.10 (M) In the assessment model, specify the proportion mature in terms of length, and compute maturity-at-age taking the distribution of length-at-age into account. Similarly, formulate quantities which depend on weight in terms of weight-at-length and account for the probability distribution for length-at-age. [Review assessment.]

A.11 (M) Consider a model in which fishery selectivity is governed by a double logistic (or double-normal) function, and where several of the parameters of this function are time-varying. [Review assessment; Is there a need for time-varying selectivity; how best is this modelled?]

A.12 (L) Evaluate the implied distributions of length-at-age given the growth curves which are fitted using the tagging data (e.g. MARAM IWS/NOV17/SCRL/BG7), and compare these distributions to the distributions of length-at-age estimated in the assessment (which assume a constant CV of length-at-age). This will involve making assumptions regarding the distributions of birth dates and of the length-at-age at birth. [Review assessment.] B. Linefish B.1 (*) The approach of Winker et al. (in press) performs well in the simulations conducted