A Proposed Set of Operating Models for Canadian Pollock in the Western Component (4Xopqrs+5Zc) to be used in Management Procedure Testing (or MSE)

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Introduction

A key feature that distinguishes the Management Procedure Approach (also termed Management Strategy Evaluation or MSE) from conventional "best assessments" is the importance of selecting not the ("best") one assessment, but rather of ensuring that future resource trends will be satisfactory no matter which of a number plausible assessments most closely reflects the actual (but unknown) underlying situation of the resource.

Frequent convention is to select a small number of such "Operating Models" (OMs), spanning the most important aspects of uncertainty in the assessment, for use as a Reference Set (RS) which provides the initial basis to develop and to tune a Management Procedure (MP).

This paper develops a suggested set of four VPA-based OMs to provide a RS to serve as a basis for subsequent testing of candidate MPs. Two Statistical Catch-at-Age (SCAA) models are also developed to provide robustness tests for MPs developed using the VPA-based RS.

Data and Methods

The details of the VPA methodology are provided in Appendix A, while those of the SCAA methodology are provided in Appendix B. The data used are listed in Appendix C.

Results

Table 1 summarises the seven OMs presented in this paper, while Table 2 compares the negative log-likelihood values for these.

VPA results and Comparisons

Stone *vs*. Rademeyer

Although both based on VPA, the analysis of Stone (Stone, 2010) use a slightly different methodology. Fig. 1 compares spawning (B4+) and exploitable biomass (B4-8), as well as fishing mortality trajectories for these two cases. The trajectories are virtually identical, except for the most recent years. The recent divergence is due to the use of a bias correction approach in the Stone analysis. These two analyses are subsequently referred to as "Base Cases".

Excluding the 2010 survey estimates

Fig. 2 compares a series of trajectories for two VPAs which either include or exclude the 2010 survey results. Here differences are much greater over recent years than for the "Stone *vs* Rademeyer" comparison above

Fishing mortality at older ages

In the Rademeyer Base Case VPA, σ_F=0.01, so that the fishing mortality on age 9 is very close to the weighted average of ages 7 and 8 fishing mortalities. Fig. 3 compares the trajectories for this analysis with those for a case when this penalty is relaxed (σ_F=0.3). There are differences as in Fig. 2, though not as large, and in particular much less for recruitment.

Choice of a VPA-based Reference Set of OMs

Fig. 4 plots the trajectories for the proposed VPA Reference Set for use in MP testing (MSE). This proposed Reference Set includes the following cases, which are VPA variants selected to attempt to span the range of uncertainties encompassed by key choices for different features of the VPA:

1) St1_BC_withBias: Stone (Stone, 2010) Base Case;

2) St2_BC_withBias_no2010: Stone (Stone, 2010), excluding the 2010 survey biomass estimates;

3) Rad1_sig001: Rademeyer Base Case;

4) Rad3_sig03: Rademeyer, with more flexibility on age 9 fishing mortality.

SCAA results

Fig. 5 compares the Rademeyer Base Case VPA results (Rad1_sig001) with two SCAA implementations: for SCAA1, the survey selectivity is assumed to decline exponentially at older ages, while for SCAA2, the survey selectivity for ages 9 and above is fixed at the age 8 level. These OMs are for use as robustness tests for Management Procedures developed through testing under the VPA-based Reference Set of OMs. Results for the Rademeyer Base Case and SCAA2 are very close, but absolute biomass estimates are generally rather larger for SCAA1.

Reference

Stone H. 2010. 2010 Pollock Assessment Update for the Western Component (4Xopqrs5). WP1.

Table 1: Summary of the Operating Models (OMs) presented.

	Type	2010 survey	bias correction	σ_F	RS	Survey selectivity
St1_withBias	VPA	included	included	-	yes	-
St2_withBias_no2010	VPA	excluded	included	-	yes	-
Rad1_sig001	VPA	included	-	0.01	yes	-
Rad2_sig001_no2010	VPA	excluded	-	0.01	-	-
Rad3_sig03	VPA	included	-	0.3	yes	-
SCAA1	SCAA	included	-	-	-	domed
SCAA2	SCAA	included	-	-	-	flat

Table 2: Components of the negative log-likelihoods for the five VPA- and two SCAA-based OMs.

	St1_ withBias	St2_ withBias_ no2010	Rad1_ sig001	Rad2_ sig001_ no2010	Rad3_ sig03		SCAA1	SCAA2
-lnL:overall	205.6	189.9	209.1	191.0	195.8	-lnL:overall	-14.0	-11.1
-lnL:RV3	50.5	52.6	50.4	53.1	49.8	-lnL:Survey	8.7	9.0
-lnL:RV4	30.7	24.0	30.1	23.5	29.4	-lnL:CPUE	-29.4	-28.9
-lnL:RV5	21.3	17.9	21.9	17.8	21.6	-lnL:CAA	-28.0	-26.7
-lnL:RV6	18.3	14.2	18.1	14.0	14.4	-lnL:CAAsurv	27.2	26.8
-lnL:RV7	26.1	22.2	24.9	20.5	17.7	-lnL:RecRes	7.6	8.7
-lnL:RV8	27.2	27.3	29.0	27.4	26.4			
-lnL:CPUE3	9.1	9.2	10.4	10.4	10.5			
-lnL:CPUE4	3.0	3.0	4.1	4.1	4.0			
-lnL:CPUE5	3.5	3.5	4.4	4.4	4.1			
-lnL:CPUE6	4.3	4.3	4.4	4.4	4.1			
-lnL:CPUE7	4.7	4.7	4.8	4.8	4.7			
-lnL:CPUE8	7.0	7.0	6.5	6.5	6.3			
F penalty	-	-	0.0	0.0	2.7			

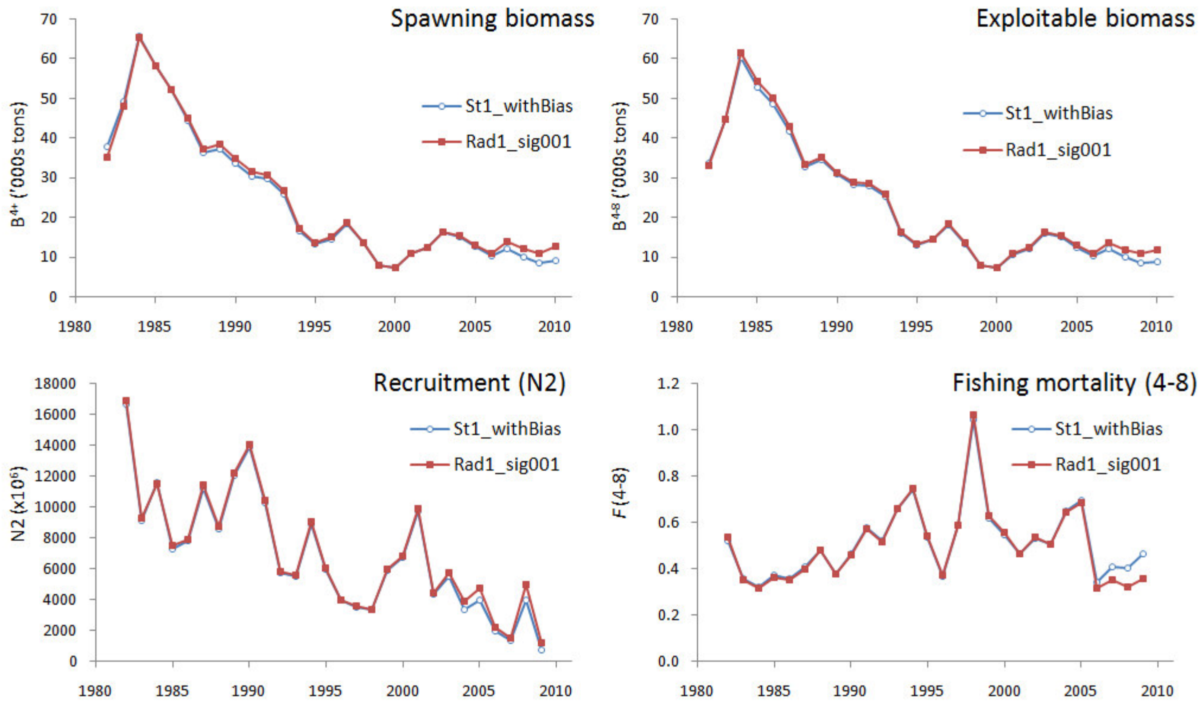

Fig. 1: Time-trajectories of spawning biomass (B4+), exploitable biomass (B4-8), recruitment (N2) and fishing mortality (ages 4-8) for the Stone (St1_withBias) and Rademeyer (Rad1_sig001) VPA Base Cases.

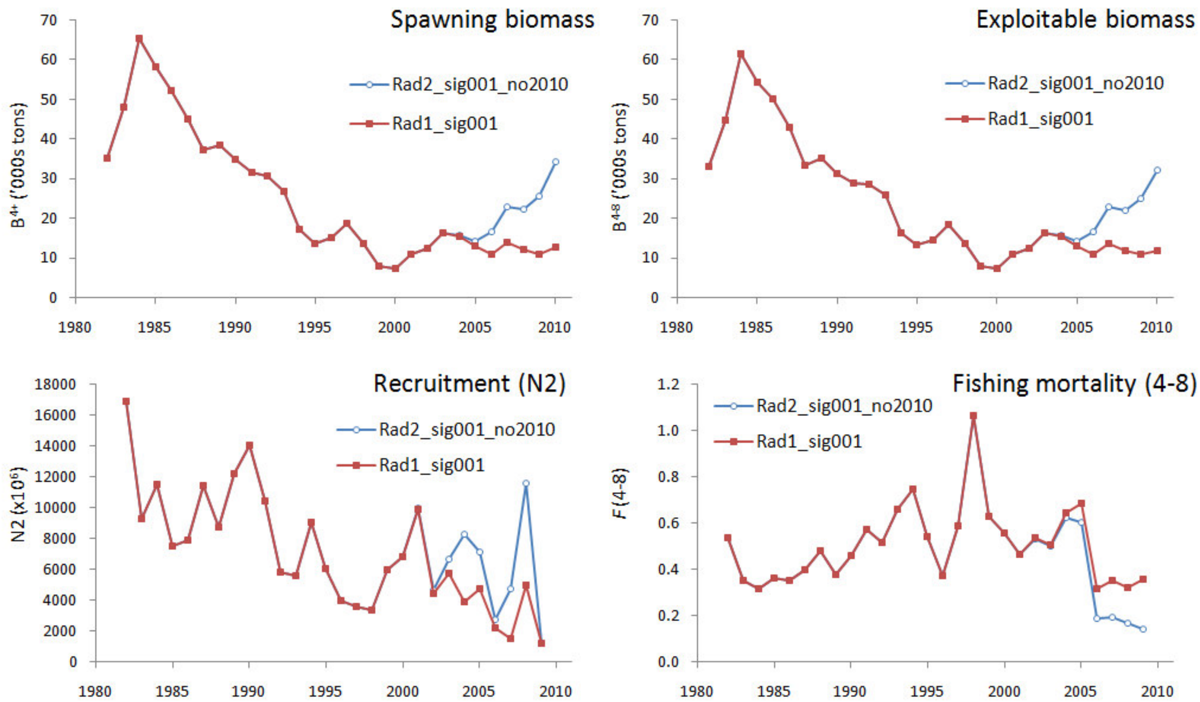

Fig. 2: Time-trajectories of spawning biomass (B4+), exploitable biomass (B4-8), recruitment (N2) and fishing mortality (ages 4-8) for the VPA assessments including (Rad1_sig001) and excluding the 2010 survey results (Rad2_sig001_no2010).

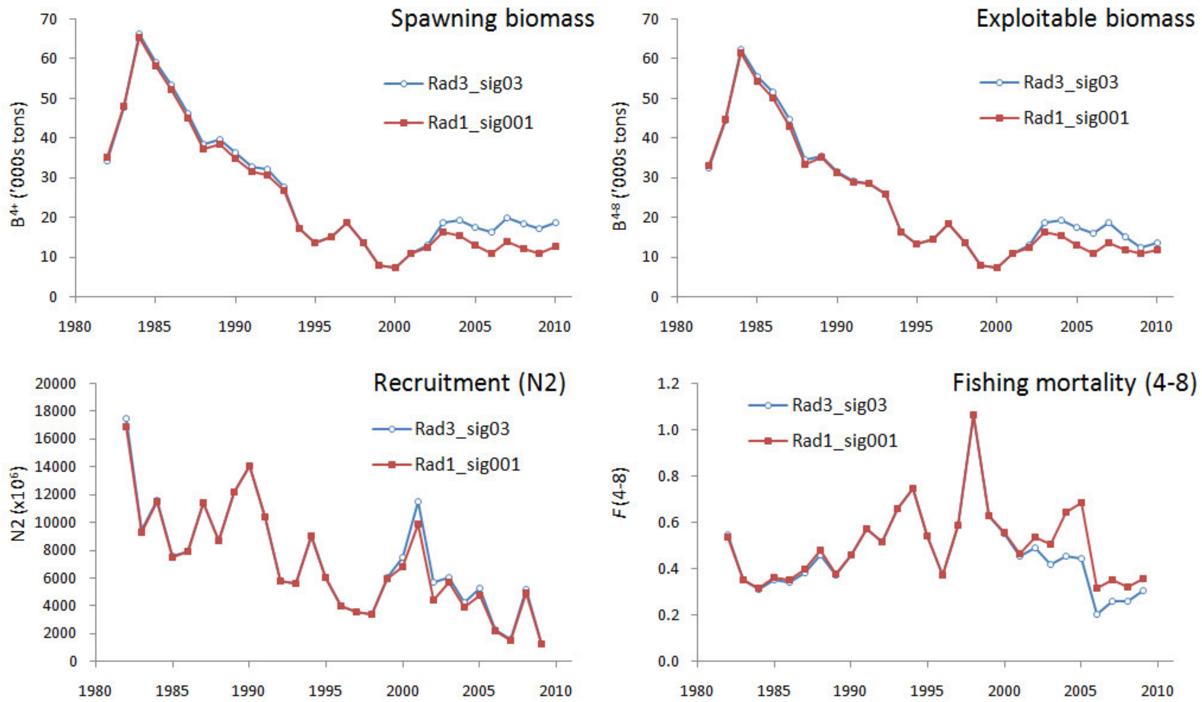

Fig. 3: Time-trajectories of spawning biomass (B4+), exploitable biomass (B4-8), recruitment (N2) and fishing mortality (ages 4-8) for the VPA-based OMs with σ_F=0.01 (Rad1_sig001) and σ_F=0.3 (Rad3_sig03).

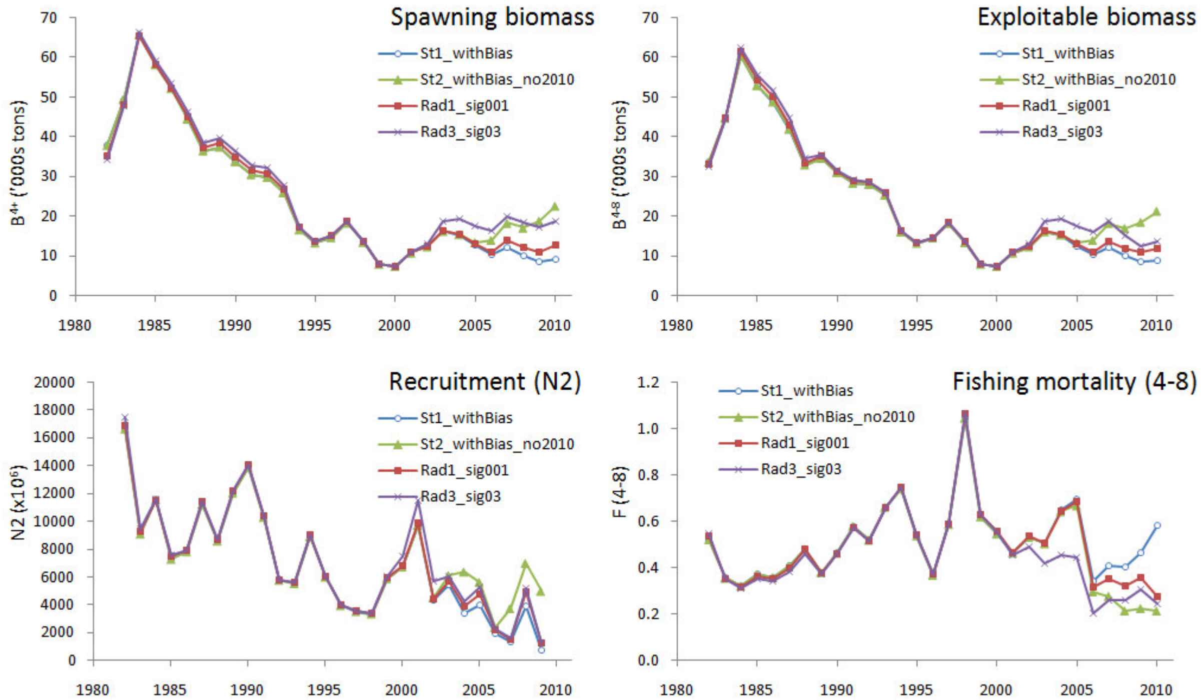

Fig. 4: Time-trajectories of spawning biomass (B4+), exploitable biomass (B4-8), recruitment (N2) and fishing mortality (ages 4-8) for the proposed VPA Reference Set of OMs.

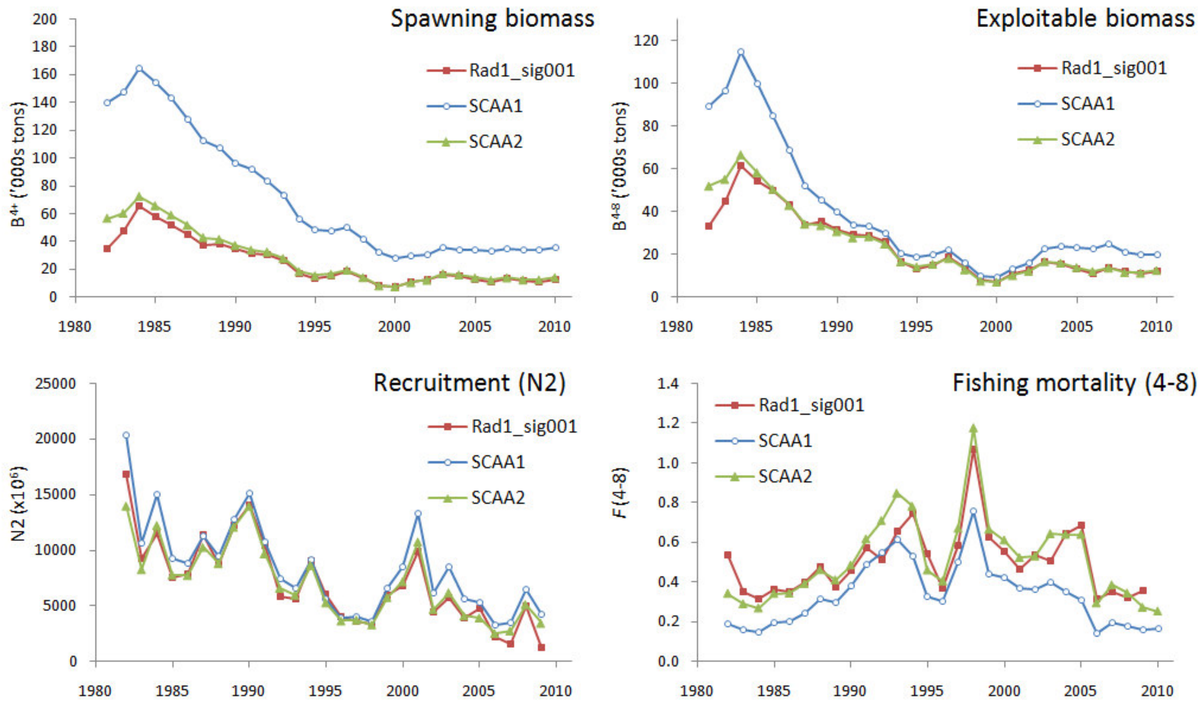

Fig. 5: Time-trajectories of spawning biomass (B4+), exploitable biomass (B4-8), recruitment (N2) and fishing mortality (ages 4-8) for the Base Case VPA and two SCAA OMs: with decreasing (SCAA1) and flat (SCAA2) survey selectivity at older ages.

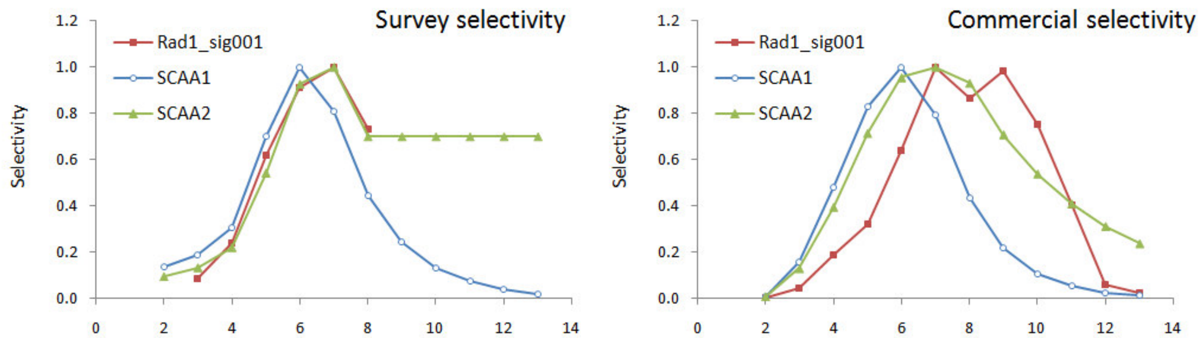

Fig. 6: Survey and commercial selectivities for the VPA Base Case and the two SCAA-based OMs.

Appendix A - The VPA Model

A.1. Population Dynamics

The resource dynamics are modelled by the following set of equations:

$$N_{y,a} = N_{y+1,a+1}e^{M_a} + C_{y,a}e^{M_a/2} \qquad \text{for } 2 \le a \le m-1 \tag{A1}$$

$$Z_{y,a} = \ell n\left(\frac{N_{y,a}}{N_{y+1,a+1}}\right) \tag{A2}$$

$$F_{y,a} = Z_{y,a} - M_a \tag{A3}$$

where

$N_{y,a}$ is the number of fish of age *a* at the start of year *y* (which refers to a calendar year),

M_a denotes the instantaneous rate of natural mortality for fish of age *a* (*M*=0.2 for all ages),

$C_{y,a}$ is the number of fish of age *a* caught in year *y*,

m is the maximum age for the estimation (age 9),

$Z_{y,a}$ is the instantaneous rate of mortality during year *y* from all causes (total mortality) on fish of age *a*, and

$F_{y,a}$ is the instantaneous rate of fishing mortality on fish of age *a*.

The total and fishing mortality on age *m*:

$$Z_{y,m} = \ell n\left(\frac{N_{y,m}}{\left(N_{y,m}e^{-M_m/2} - C_{y,m}\right)e^{-M_m/2}}\right) \tag{A4}$$

$$F_{y,m} = Z_{y,m} - M_m \tag{A5}$$

Catch-at-age information is available to age 13, so that the numbers-at-age for ages 10 to 13 (not taken to be a plus-group) can be computed as:

$$N_{y+1,a} = \left(N_{y,a-1}e^{-M_{a-1}/2} - C_{y,a-1}\right)e^{-M_{a-1}/2} \qquad 10 \le a \le 13 \tag{A6}$$

A.2. The Objective Function

The model is fit to survey abundance and CPUE indices. Contributions by each of these to the objective function (maximised in the fit) are computed as follows.

Calculations assume that the observed abundance indices are log-normally distributed about their expected values:

$$I^i_{y,a} = \hat{I}^i_{y,a}\exp\left(\varepsilon^i_{y,a}\right) \quad \text{or} \quad \varepsilon^i_{y,a} = \ell\text{n}\left(I^i_{y,a}\right) - \ell\text{n}\left(\hat{I}^i_{y,a}\right) \tag{A7}$$

where

$I^i_{y,a}$ is the observed abundance index for year *y*, age *a* and series *i*,

$\hat{I}^i_{y,a}$ is the corresponding model estimate, where

$$\hat{I}^i_{y,a} = q^i_a N_{y,a} \frac{1-e^{-Z_{y,a}}}{Z_{y,a}} \quad \text{for survey mid-year indices, and} \tag{A8}$$

$$\hat{I}^i_{y,a} = q^i_a \left(N_{y,a} \frac{1-e^{-Z_{y,a}}}{Z_{y,a}} \right)^{\beta^i_a} \quad \text{for CPUE mid-year indices.} \tag{A9}$$

β^i_a are estimable parameters, and

$\hat{q}^i_a$ is the constant of proportionality (catchability) for abundance series *i* and age *a*, estimated by its maximum likelihood value:

$$\ln\left(\hat{q}^i_a\right) = \sum_y \left[\ln\left(I^i_{y,a}\right) - \ln\left[\left(N_{y,a} \frac{1-e^{-Z_{y,a}}}{Z_{y,a}} \right)^{\beta^i_a} \right] \right] \Big/ \sum_y 1 \tag{A10}$$

The objective function is then given by:

$$SS = \sum_{i,y,a} \left[\ell n\left(I^i_{y,a}\right) - \ell n\left(\hat{I}^i_{y,a}\right) \right]^2$$

The function is minimised by treating the abundances for ages 3 to 8 in year *T*+1 as estimable parameters, where *T* is the final year. Furthermore, the $N_{y,m}$ are estimated directly for each year to year *T* and a penalty is added to the objective function:

$$P = \sum_y \left[\ln\left(F_{y,m}\right) - \ln\left(\hat{F}_{y,m}\right) \right]^2 \Big/ 2\sigma^2_F \tag{A11}$$

where

$$\hat{F}_{y,m} = 0.5\left(F_{y,m-2} + F_{y,m-1}\right) \quad \text{(i.e. asymptotically flat selectivity)} \tag{A12}$$

σ_F is set small.

Appendix B - The Statistical Catch-at-Age Model

B.1 Population dynamics

The resource dynamics are modelled by the following set of population dynamics equations:

$$N_{y+1,2} = R_{y+1} \qquad \text{(B1)}$$

$$N_{y+1,a+1} = \left(N_{y,a}\, e^{-M_a/2} - C_{y,a}\right) e^{-M_a/2} \qquad \text{for } 2 \le a \le m-2 \qquad \text{(B2)}$$

$$N_{y+1,m} = \left(N_{y,m-1}\, e^{-M_{m-1}/2} - C_{y,m-1}\right) e^{-M_{m-1}/2} + \left(N_{y,m}\, e^{-M_m/2} - C_{y,m}\right) e^{-M_m/2} \qquad \text{(B3)}$$

where

$N_{y,a}$ is the number of fish of age *a* at the start of year *y* (which refers to a calendar year),

R_y is the recruitment (number of 2-year-old fish) at the start of year *y*,

M_a denotes the natural mortality rate for fish of age *a*,

$C_{y,a}$ is the predicted number of fish of age *a* caught in year *y*, and

m is the maximum age considered (13, taken to be a plus-group).

The number of recruits (i.e. new 2-year old fish) at the start of year *y* is assumed to be related to the spawning stock size (i.e. the biomass of mature fish) by a Beverton-Holt stock-recruitment relationship, allowing for annual fluctuation about the deterministic relationship:

$$R_y = \frac{\alpha B_{y-2}^{sp}}{\beta + B_{y-2}^{sp}}\, e^{(\varsigma_y - (\sigma_R)^2/2)} \qquad \text{(B4)}$$

where

α and β are spawning biomass-recruitment relationship parameters,

ς_y reflects fluctuation about the expected recruitment for year *y*, which is assumed to be normally distributed with standard deviation σ_R (which is input (0.5) in the applications considered here); these residuals are treated as estimable parameters in the model fitting process.

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

$$B_y^{sp} = \sum_{a=2}^{m} f_{y,a}\, w_{y,a}^{strt} N_{y,a} \qquad \text{(B5)}$$

where

$w_{y,a}^{strt}$ is the mass of fish of age *a* during spawning, and

$f_{y,a}$ is the proportion of fish of age *a* that are mature.

In order to work with estimable parameters that are more meaningful biologically, the stock-recruitment relationship is re-parameterised in terms of the pre-exploitation equilibrium spawning biomass, K^{sp}, and the "steepness", *h*, of the stock-recruitment relationship, which is the proportion of the virgin recruitment that is realized at a spawning biomass level of 20% of the virgin spawning biomass. In the fitting procedure, both *h* and K^{sp} are estimated, with h constrained not to exceed 0.9.

The catch by mass in year *y* is given by:

$$C_y = \sum_{a=2}^{m} w_{y,a}^{mid}\ C_{y,a} = \sum_{a=2}^{m} w_{y,a}^{mid}\ N_{y,a}\ e^{-M_a/2}\ S_{y,a}\ F_y^* \qquad \text{(B6)}$$

where

$w_{y,a}^{mid}$ denotes the mass of fish of age *a* landed in year *y*,

$C_{y,a}$ is the catch-at-age, i.e. the number of fish of age *a*, caught in year *y*,

$S_{y,a}$ is the commercial selectivity (i.e. combination of availability and vulnerability to fishing gear) at age *a* for year *y*; when $S_{y,a} = 1$, the age-class *a* is said to be fully selected, and

F_y^* is the proportion of a fully selected age class that is fished.

The model estimate of the mid-year exploitable ("available") component of biomass is:

$$B_y^{ex} = \sum_{a=2}^{m} w_{y,a}^{mid} S_{y,a} N_{y,a} e^{-M_a/2}(1 - S_{y,a}F_y^*/2) \qquad \text{(B7)}$$

whereas for survey estimates of biomass in the middle of the year:

$$B_y^{surv} = \sum_{a=2}^{m} w_{y,a}^{mid} S_a^{surv} N_{y,a} e^{-M_a/2}(1 - S_{y,a}F_y^*/2) \qquad \text{(B8)}$$

where

S_a^{surv} is the year-independent survey selectivity for age *a*.

Initial conditions

As the first year for which data (even annual catch data) are available for the stock considered clearly does not correspond to the first year of (appreciable) exploitation, one cannot make the conventional assumption in the application of ASPM's that this initial year reflects a population (and its age-structure) at pre-exploitation equilibrium. For the first year (y_0) considered in the model therefore, the stock is assumed to be at a fraction (θ) of its pre-exploitation biomass, i.e.:

$$B_{y_0}^{sp} = \theta \cdot K^{sp} \qquad \text{(B9)}$$

with the starting age structure:

$$N_{y_0,a} = R_{start} N_{start,a} \quad \text{for } 2 \le a \le m \tag{B10}$$

where

$$N_{start,2} = 1 \tag{B11}$$

$$N_{start,a} = N_{start,a-1} e^{-M_{a-1}} (1-\phi S_{a-1}) \quad \text{for } 3 \le a \le m-1 \tag{B12}$$

$$N_{start,m} = N_{start,m-1} e^{-M_{m-1}} (1-\phi S_{m-1}) \Big/ (1-e^{-M_m}(1-\phi S_m)) \tag{B13}$$

where ϕ characterises the average fishing proportion over the years immediately preceding y_0.

B.2. The (penalised) likelihood function

The model is fit to CPUE and survey abundance indices, and commercial and survey catch-at-age data to estimate model parameters. Contributions by each of these to the negative of the (penalised) log-likelihood (- $\ell\text{n}L$) are as follows.

CPUE relative abundance data

The likelihood is calculated assuming that an observed CPUE abundance index for a particular fishing fleet is log-normally distributed about its expected value:

$$I_y^i = \hat{I}_y^i \exp\left(\varepsilon_y^i\right) \quad \text{or} \quad \varepsilon_y^i = \ell\text{n}\left(I_y^i\right) - \ell\text{n}\left(\hat{I}_y^i\right) \tag{B14}$$

where

I_y^i is the CPUE abundance index for year *y* and series *i*,

$\hat{I}_y^i = \hat{q}^i \left(\hat{B}_y^{ex}\right)^{\beta^i}$ is the corresponding model estimate, where $\hat{B}_y^{ex}$ is the model estimate of exploitable resource biomass, given by equation (B7),

$\hat{q}^i$ is the constant of proportionality (catchability) for CPUE abundance series *i*,

β^i is an estimable parameter and

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

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

$$-\ell\text{n}\, L^{CPUE} = \sum_i \sum_y \left[\ell\text{n}\left(\sigma_y^i\right) + \left(\varepsilon_y^i\right)^2 / 2\left(\sigma_y^i\right)^2\right] \tag{B15}$$

where

σ_y^i is the standard deviation of the residuals for the logarithm of index *i* in year *y*.

Homoscedasticity of residuals is assumed, so that $\sigma_y^i = \sigma^i$ is estimated in the fitting procedure by its maximum likelihood value:

$$\hat{\sigma}^i = \sqrt{1/n_i \sum_y \left(\ell\text{n}(I_y^i) - \ell\text{n}(q^i \hat{B}_y^{ex})\right)^2} \tag{B16}$$

where

n_i is the number of data points for CPUE abundance index *i*.

The catchability coefficient q^i for CPUE abundance index *i* is estimated by its maximum likelihood value:

$$\ell n\, \hat{q}^i = 1/n_i \sum_y \left(\ln I_y^i - \ln \hat{B}_y^{ex}\right) \quad \text{(B17)}$$

Survey abundance data

In general, data from the surveys are treated as relative abundance indices in the same manner to the CPUE series above, but with

$$\hat{I}_y^i = \hat{q}^i \hat{B}_y^{surv} \quad \text{(B18)}$$

Commercial catches-at-age

The contribution of the catch-at-age data to the negative of the log-likelihood function under the assumption of an "adjusted" lognormal error distribution is given by:

$$-\ell n L^{CAA} = \sum_y \sum_a \left[\ell n\left(\sigma_{com} / \sqrt{p_{y,a}}\right) + p_{y,a}\left(\ell n\, p_{y,a} - \ell n\, \hat{p}_{y,a}\right)^2 / 2\left(\sigma_{com}\right)^2 \right] \quad \text{(B19)}$$

where

$p_{y,a} = C_{y,a} / \sum_{a'} C_{y,a'}$ is the observed proportion of fish caught in year *y* that are of age *a*,

$\hat{p}_{y,a} = \hat{C}_{y,a} / \sum_{a'} \hat{C}_{y,a'}$ is the model-predicted proportion of fish caught in year *y* that are of age *a*,

where

$$\hat{C}_{y,a} = N_{y,a}\, e^{-M_a/2}\, S_{y,a}\, F_y \quad \text{(B20)}$$

and

σ_{com} is the standard deviation associated with the catch-at-age data, which is estimated in the fitting procedure by:

$$\hat{\sigma}_{com} = \sqrt{\sum_y \sum_a p_{y,a}\left(\ell n\, p_{y,a} - \ell n\, \hat{p}_{y,a}\right)^2 / \sum_y \sum_a 1} \quad \text{(B21)}$$

Commercial catches-at-age are incorporated in the likelihood function using equation A2.19, for which the summation over age *a* is taken from age a_{minus} (considered as a minus group) to a_{plus} (a plus group).

Survey catches-at-age

The survey catches-at-age 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 B19) where:

$p_{y,a} = C^{surv}_{y,a} / \sum_{a'} C^{surv}_{y,a'}$ is the observed proportion of fish of age *a* in year *y*,

$\hat{p}_{y,a}$ is the expected proportion of fish of age *a* in year *y* in the survey, given by:

$$\hat{p}_{y,a} = \hat{C}^{surv}_{y,a} / \sum_{a'} \hat{C}^{surv}_{y,a'}$$

where

$$\hat{C}^{surv}_{y,a} = S^{surv}_a N_{y,a} e^{-M_a/2}\left(1 - F^*_{y,a}/2\right) \quad \text{for mid-year surveys.} \qquad \text{(B21)}$$

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 (now penalised) log-likelihood function is given by:

$$-\ell n L^{pen} = \sum_{y=y1}^{y2} \left[(\varepsilon_y)^2 / 2\sigma_R^2\right] \qquad \text{(B22)}$$

where

ε_y is the recruitment residual for year *y*, which is estimated for year *y*1 to *y*2 (see eqn B4),

σ_R is the standard deviation of the log-residuals, which is input (0.5).

The years y_1 and y_2 are chosen to include periods to which age data relate and hence provide some information on the recruitment residuals.

B.3. Model parameters

Fishing selectivity-at-age:

The commercial fishing selectivity, S_a, is estimated separately for ages 2-9, while the fishing selectivity for the surveys, S^{surv}_a, is estimated separately for ages 2-8. If not indicated otherwise, the estimated decrease from ages 8 to 9 for the commercial selectivity and from ages 7 to 8 for the survey selectivity is assumed to continue exponentially to age 13.

Other parameters

Plus-group:	m	13
Commercial CAA:	a_{minus}	2
	a_{plus}	9
Survey CAA:	a_{minus}	2
	a_{plus}	8
Stock-recruitment residuals:	σ_R	0.5
	y_1	1983
	y_2	2009
Natural mortality:	M	0.2
	Maturity-at-age:	
Maturity-at-age:	$f_{y,a}$	knife-edge, 1 for ages 4 and above
Weight-at-age:	$w^{sp}_{y,a}$	input, see Table C1
	$w^{landed}_{y,a}$	input, see Table C2

Appendix C - The Data

Table C1: Begin-year weight-at-age (kg) in the western component (4Xopqrs+5Zc) (used in VPA and SCAA).

	2	3	4	5	6	7	8	9	10	11	12	13
1982	0.2837	0.8110	1.6927	2.9881	3.8182	4.4827	5.2067	5.9535	6.9253	8.1411	9.5694	10.8088
1983	0.3032	1.2351	1.6599	2.9494	3.8883	4.6365	5.1929	6.1344	6.7116	8.0265	8.7530	10.8088
1984	0.3602	0.9441	2.6147	2.7299	3.7088	4.8566	5.5630	5.9230	6.6425	7.2250	9.0280	9.8867
1985	0.3229	0.8066	2.3010	2.8995	3.3322	4.1856	5.7031	6.6591	6.6787	7.2852	8.2189	10.3429
1986	0.4231	0.8998	1.6075	3.1362	3.5286	4.0913	4.9878	6.3287	7.2376	7.2532	8.3250	10.1377
1987	0.1852	0.6416	1.8835	2.5537	3.3212	4.1175	4.7147	5.5401	6.7221	7.3197	7.6098	9.7815
1988	0.5720	0.6959	1.3640	2.7042	3.4053	3.8648	4.6351	5.3743	6.1227	7.4498	7.9532	9.3273
1989	0.3658	0.7501	1.9007	2.6880	3.4681	4.1349	4.5173	5.4712	6.1059	7.9390	7.6334	9.6433
1990	0.2538	0.6563	1.3228	2.7839	3.3496	4.3030	5.1116	5.5696	6.4714	6.9496	9.3306	8.8579
1991	0.3662	0.5902	1.1540	2.4162	3.2882	4.1590	5.2171	6.1306	6.5893	7.4931	8.2978	10.3668
1992	0.3305	0.7757	1.3741	1.9904	3.1712	4.1519	5.0847	5.9221	6.6589	7.4591	8.6060	9.9664
1993	0.4443	0.5595	1.1683	2.2024	2.8669	3.6294	4.6682	5.4790	6.4163	7.2719	8.1475	10.0538
1994	0.3093	0.6933	1.1076	1.6171	2.6590	3.4400	3.9797	4.7881	5.8672	6.3854	7.7747	9.4573
1995	0.2125	0.4816	1.1834	1.9669	2.5634	3.4715	4.2493	4.7682	5.9722	7.3305	7.3079	9.2901
1996	0.2000	0.6133	1.0421	1.9506	2.6493	3.3368	4.5291	5.4951	6.7688	8.3818	9.8955	9.8281
1997	0.2039	0.9740	1.3395	2.1024	2.7815	3.4863	4.3238	6.3566	7.9577	7.5682	10.6733	11.2090
1998	0.3747	0.6042	0.9712	2.0163	2.7731	3.7245	4.5290	5.3637	8.1779	9.4256	9.0149	11.4484
1999	0.2215	0.6072	1.1906	1.8277	2.7679	3.6717	4.8862	6.0338	7.4871	9.2552	9.3984	11.5192
2000	0.2636	0.6972	1.2087	1.8378	2.7674	3.6777	4.8173	5.7018	7.9708	9.8798	9.9715	10.4881
2001	0.3130	0.5250	1.4793	2.3528	3.0419	3.8881	5.2178	6.6283	7.0040	9.0145	10.2932	10.4881
2002	0.2574	0.6045	1.1730	2.1147	3.2982	4.2463	5.4969	6.7310	8.3861	9.6351	10.0009	10.8935
2003	0.2201	0.7083	1.1751	2.1005	2.9864	4.2134	5.5109	6.8555	8.0233	9.3493	9.8229	11.0404
2004	0.2052	0.5661	1.4299	1.9061	2.7249	3.8904	5.5779	6.8076	8.0379	9.1784	11.0160	9.8805
2005	0.2269	0.5969	1.2428	1.8905	2.4648	3.5422	4.7240	6.1204	8.0829	11.1443	11.3839	11.5020
2006	0.3502	0.7017	1.3926	1.9257	2.5238	3.1957	4.3348	5.1940	7.2451	9.3716	12.4467	12.5318
2007	0.2232	0.6997	1.4407	2.1906	2.5424	3.4901	4.1181	5.4222	6.1747	9.6431	11.3877	10.9252
2008	0.3701	0.7717	1.3424	1.9664	2.8352	3.3650	4.3903	5.0344	6.1317	8.0581	10.9793	12.0000
2009	0.4550	0.8687	1.6664	2.1132	2.7619	3.6404	4.1722	4.9898	5.4368	8.4602	10.7045	11.4046
2010	0.0731	0.7495	1.5500	2.1800	2.7525	3.5527	4.2543	4.5143	5.0212	5.8213	11.0727	11.9463

Table C2: Mid-year weight-at-age (kg) in the western component (4Xopqrs+5Zc) (used in VPA and SCAA).

	2	3	4	5	6	7	8	9	10	11	12	13
1982	0.943	1.427	2.529	3.462	4.211	4.772	5.681	6.239	7.687	8.622	10.621	10.802
1983	0.881	1.349	1.983	3.373	4.367	5.105	5.651	6.624	7.220	8.381	8.886	9.188
1984	0.914	1.635	2.331	3.005	4.078	5.401	6.062	6.208	6.661	7.230	9.725	8.091
1985	0.974	1.615	2.462	3.169	3.695	4.296	6.022	7.315	7.185	7.968	9.343	9.401
1986	0.738	1.554	2.306	3.095	3.929	4.530	5.791	6.651	7.161	7.322	8.698	6.835
1987	0.943	1.475	2.266	3.046	3.564	4.315	4.907	5.300	6.794	7.482	7.909	8.806
1988	1.195	1.549	2.240	3.096	3.807	4.191	4.979	5.886	7.073	8.169	8.454	8.467
1989	0.880	1.313	2.095	3.068	3.885	4.491	4.869	6.012	6.334	8.911	7.133	10.715
1990	0.571	1.263	2.055	2.894	3.657	4.766	5.818	6.371	6.966	7.625	9.770	9.070
1991	0.906	1.344	2.153	2.866	3.736	4.730	5.711	6.460	6.815	8.060	9.030	9.778
1992	1.033	1.271	1.831	2.615	3.509	4.614	5.466	6.141	6.864	8.164	9.189	8.947
1993	0.761	1.110	1.666	2.312	3.143	3.754	4.723	5.492	6.704	7.704	8.131	8.606
1994	0.805	1.250	1.586	2.163	3.058	3.765	4.219	4.854	6.268	6.082	7.846	8.539
1995	0.671	1.132	1.806	2.296	3.038	3.941	4.796	5.389	7.348	8.573	8.781	9.392
1996	0.896	1.336	1.795	2.353	3.057	3.665	5.205	6.296	8.502	9.561	11.422	11.474
1997	0.915	1.388	1.938	2.446	3.288	3.976	5.101	7.763	10.058	6.737	11.915	11.000
1998	0.867	1.103	1.720	2.361	3.144	4.219	5.159	5.640	8.615	8.833	12.063	11.000
1999	0.806	1.193	1.682	2.419	3.245	4.288	5.659	7.057	9.939	9.943	10.000	11.000
2000	0.757	1.247	1.796	2.478	3.166	4.168	5.412	5.745	9.003	9.821	10.000	11.000
2001	0.453	1.039	1.987	2.929	3.734	4.775	6.532	8.118	8.539	9.026	10.788	13.067
2002	0.280	0.931	1.592	2.528	3.714	4.829	6.328	6.936	8.663	10.872	11.081	16.975
2003	0.590	0.977	1.536	2.376	3.528	4.780	6.289	7.427	9.281	10.090	8.875	11.000
2004	0.475	0.873	1.621	2.210	3.125	4.290	6.509	7.369	8.699	9.077	12.027	15.595
2005	0.391	0.955	1.439	2.152	2.801	4.087	5.479	5.956	9.216	14.277	14.277	11.000
2006	0.654	0.931	1.722	2.180	3.101	3.715	4.680	5.186	9.121	9.906	10.851	11.000
2007	0.660	0.948	1.573	2.525	2.973	3.944	4.567	6.229	7.352	10.195	13.091	11.000
2008	0.758	1.202	1.681	2.299	3.191	3.819	4.907	5.552	5.985	8.832	11.824	11.000
2009	0.585	1.137	1.884	2.451	3.318	4.153	4.558	5.074	5.324	11.959	12.974	13.123
2010	0.683	1.026	1.754	2.456	3.091	3.804	4.358	4.471	4.969	6.365	10.252	11.000

Table C2: Pollock landings (tons) in the western component (4Xopqrs+5Zc) (used in SCAA only).

year	catch	year	catch	year	catch
1982	18347	1992	16639	2002	6485
1983	16448	1993	14410	2003	7839
1984	15291	1994	10836	2004	8012
1985	19511	1995	7144	2005	6928
1986	17520	1996	6441	2006	3469
1987	16460	1997	9759	2007	4679
1988	17899	1998	10534	2008	4115
1989	13724	1999	4760	2009	3819
1990	15595	2000	4768	2010	3218
1991	18602	2001	5400		

Table C3: Pollock total catch-at-age (000s) in the western component (4Xopqrs+5Zc) (used in VPA and SCAA).

year	2	3	4	5	6	7	8	9	10	11	12	13
1982	95.41	1618.04	1351.70	371.41	1031.13	838.11	425.02	145.46	45.18	33.17	12.93	0.00
1983	44.95	1282.78	3965.86	853.58	179.05	313.82	291.22	138.23	59.16	17.35	18.61	0.00
1984	3.79	370.37	1831.89	2751.15	464.92	85.42	148.40	114.32	40.69	18.58	2.22	0.00
1985	4.64	194.79	621.34	1805.50	2142.31	327.53	37.57	100.11	99.06	62.26	29.79	0.00
1986	1.24	162.33	1410.04	1136.24	1328.96	876.49	87.70	36.68	36.68	41.43	15.09	0.00
1987	4.90	104.10	627.83	1622.12	883.39	786.09	490.10	68.45	16.94	15.46	27.74	0.00
1988	18.85	424.56	989.57	1125.72	1280.52	518.57	423.85	242.26	22.02	14.30	20.44	0.00
1989	93.26	386.48	1532.79	1128.98	575.96	463.10	147.11	129.18	65.05	6.08	7.43	0.00
1990	47.02	776.37	1102.18	1620.50	873.25	429.13	173.92	138.31	49.11	23.36	9.65	0.00
1991	57.71	1013.03	1900.25	1505.91	1395.02	346.60	157.44	55.70	48.67	25.24	9.95	0.00
1992	45.61	1250.38	2678.13	1650.93	674.64	313.60	123.60	96.26	60.73	14.49	11.51	0.00
1993	4.22	550.94	1989.43	2124.58	1143.06	317.66	92.41	27.11	10.45	6.64	5.93	0.00
1994	50.53	259.40	675.15	1327.34	1151.03	494.11	166.14	58.59	14.37	7.94	1.65	0.00
1995	23.76	263.41	536.92	948.60	676.46	293.62	63.26	17.26	3.56	1.08	0.56	0.00
1996	14.06	201.70	949.14	709.71	472.61	256.04	54.80	15.08	0.32	0.06	0.61	0.00
1997	6.32	151.29	899.72	1654.37	780.40	216.96	53.59	4.31	0.37	0.93	0.06	0.00
1998	6.63	228.15	828.70	1368.31	1261.98	306.59	46.65	16.18	1.99	0.83	0.12	0.00
1999	12.54	88.92	496.43	621.11	425.96	172.65	21.53	4.13	1.18	1.94	0.00	0.00
2000	85.66	581.26	403.77	592.03	319.42	138.93	27.25	6.24	0.92	0.19	0.00	0.00
2001	15.38	335.32	813.63	571.05	313.71	90.72	13.76	4.57	1.75	0.64	0.59	0.00
2002	7.18	190.79	786.90	1072.99	416.33	126.79	19.75	5.85	1.26	0.48	0.23	0.00
2003	2.11	111.18	1301.65	1330.90	513.01	119.70	18.20	5.50	1.16	1.39	0.24	0.00
2004	1.94	173.12	542.48	1875.64	695.72	118.23	12.77	4.29	1.66	1.31	0.47	0.01
2005	0.33	36.80	842.34	758.66	1159.79	169.51	13.20	4.59	0.52	0.01	0.01	0.00
2006	0.78	29.79	153.65	533.99	353.37	218.13	18.16	2.91	0.19	0.04	0.00	0.00
2007	5.46	68.63	369.61	452.51	618.75	223.01	28.43	2.74	0.59	0.28	0.01	0.00
2008	20.42	97.38	175.36	390.39	428.88	260.49	51.70	11.49	0.54	0.05	0.00	0.00
2009	25.06	336.37	295.95	291.00	356.52	156.97	50.50	7.49	2.18	0.01	0.01	0.01
2010	10.26	119.03	266.43	293.42	208.99	213.24	62.09	29.21	6.29	0.51	0.04	0.00

Table C4: Standardized mobile gear CPUE (TC1-3) (truncated at 2004 due to changes in management measures and fishing practices) and summer survey index (Needler time series only) (used in SCAA only).

	CPUE series (tons/hour)	Survey (numbers/tow)
1982	0.1614	-
1983	0.1783	-
1984	0.2231	9.41
1985	0.1815	8.67
1986	0.1933	12.28
1987	0.1795	7.60
1988	0.1357	22.72
1989	-	7.01
1990	0.1126	66.26
1991	0.1411	12.83
1992	0.1060	4.83
1993	0.0948	36.94
1994	0.0885	7.11
1995	0.1100	6.66
1996	0.1341	30.15
1997	0.1114	3.85
1998	0.0747	2.30
1999	0.0504	3.35
2000	0.0572	7.23
2001	0.0648	14.57
2002	0.1060	3.79
2003	0.1010	9.87
2004	0.0876	9.58
2005	-	5.62
2006	-	45.66
2007	-	8.83
2008	-	12.95
2009	-	15.60
2010	-	1.94

Table C5: Summer survey index (ages 3-8) (numbers/tow) and standardized mobile gear CPUE (ages 3-8) (truncated at 2004 due to changes in management measures and fishing practives (weight/tow).

age	Survey 3	Survey 4	Survey 5	Survey 6	Survey 7	Survey 8	CPUE 3	CPUE 4	CPUE 5	CPUE 6	CPUE 7	CPUE 8
1982	0	0	0	0	0	0	1.729	1.053	0.249	0.713	0.636	0.346
1983	0	0	0	0	0	0	1.610	4.732	0.827	0.119	0.188	0.189
1984	0.545	0.951	3.308	0.913	0.097	0.284	0.391	2.169	3.517	0.628	0.114	0.186
1985	0.101	0.498	2.844	3.613	0.747	0.000	0.164	0.589	1.869	2.147	0.307	0.026
1986	1.468	1.930	1.599	3.027	1.821	0.072	0.214	1.580	1.282	1.493	0.963	0.082
1987	0.064	0.633	1.851	1.119	2.268	1.159	0.147	0.879	1.907	0.940	0.827	0.506
1988	1.651	2.277	6.218	5.278	4.043	1.984	0.200	0.570	0.927	1.124	0.418	0.352
1989	0.098	0.488	1.359	1.957	1.868	0.568	0	0	0	0	0	0
1990	15.197	6.864	10.383	2.456	0.619	0.755	0.837	1.105	1.388	0.612	0.230	0.076
1991	1.872	1.656	2.877	2.862	0.890	0.800	0.591	1.648	1.280	1.014	0.246	0.118
1992	0.364	0.989	1.341	1.061	0.223	0.143	1.045	2.455	1.245	0.328	0.091	0.028
1993	11.942	8.135	4.141	1.815	0.514	0.017	0.479	1.875	1.604	0.599	0.131	0.040
1994	0.301	1.086	2.306	1.980	0.784	0.219	0.275	0.658	1.195	0.952	0.370	0.126
1995	1.501	1.216	1.957	0.986	0.297	0.050	0.710	1.089	1.665	0.966	0.342	0.074
1996	1.142	12.519	10.772	3.475	1.531	0.133	0.511	2.618	1.797	0.896	0.393	0.061
1997	0.351	0.477	1.616	0.763	0.081	0.090	0.217	1.295	2.218	0.781	0.182	0.031
1998	0.126	0.306	0.616	0.609	0.143	0.000	0.153	0.729	1.153	0.906	0.164	0.025
1999	0.538	0.849	0.492	0.378	0.271	0.000	0.083	0.691	0.830	0.461	0.122	0.012
2000	0.480	0.439	0.795	0.216	0.000	0.029	0.979	0.657	0.823	0.344	0.112	0.020
2001	6.976	1.825	0.652	0.177	0.093	0.022	0.582	1.323	0.681	0.311	0.070	0.012
2002	1.583	0.731	0.580	0.200	0.106	0.024	0.235	1.453	2.001	0.609	0.154	0.024
2003	0.904	6.055	2.146	0.491	0.021	0.024	0.172	2.104	1.943	0.548	0.090	0.012
2004	2.462	1.438	3.659	1.347	0.313	0.000	0.248	0.735	2.381	0.667	0.077	0.007
2005	0.083	1.228	1.349	2.412	0.420	0.000	0	0	0	0	0	0
2006	0.897	10.378	22.111	8.642	3.219	0.201	0	0	0	0	0	0
2007	0.068	0.751	3.244	3.763	0.668	0.108	0	0	0	0	0	0
2008	0.210	0.489	4.298	5.222	2.008	0.134	0	0	0	0	0	0
2009	1.088	2.056	3.570	4.877	2.614	0.024	0	0	0	0	0	0
2010	0.124	0.561	0.107	0.428	0.427	0.036	0	0	0	0	0	0

Table C6: Summer DFO research vessel survey age-disaggregated numbers per tow in the western component (4Xopqrs+5Zc) (used in SCAA only).

year	2	3	4	5	6	7	8	9	10	11	12	13
1982	0	0	0	0	0	0	0	0	0	0	0	0
1983	0	0	0	0	0	0	0	0	0	0	0	0
1984	1815943	623387	1087967	3783309	1043731	111296	324838	1238612	490607	0	0	179955
1985	0	115778	569309	3252782	4132615	854066	0	367171	111648	170971	250594	76850
1986	2283026	1679390	2206877	1828601	3462190	2082570	82434	50155	45361	19977	47581	39606
1987	41643	73275	723470	2117385	1279612	2594316	1325185	65444	120459	44724	89447	168076
1988	90124	1887821	2604828	7112096	6036667	4624461	2269427	816569	168138	0	23366	271572
1989	77569	111816	557869	1553780	2238150	2136999	649296	376228	153478	0	41133	65480
1990	33595136	17381151	7850430	11875218	2808651	707814	863983	219539	124437	89466	101716	107549
1991	1404260	2140553	1894000	3290489	3273796	1017585	914965	405326	147497	78538	18352	0
1992	538504	416083	1131382	1533504	1213184	254941	163608	34577	89227	44613	106788	0
1993	11592044	13658111	9304680	4736459	2076393	587609	18867	97753	0	0	0	32233
1994	246603	344080	1241671	2637386	2264323	896821	250951	157061	60760	0	0	30380
1995	520499	1716700	1390598	2238049	1127558	339242	57260	95844	58641	0	0	0
1996	650936	1365298	14177223	12229455	3895862	1715792	196984	0	0	0	0	0
1997	495793	401073	545564	1848631	872885	92487	103148	0	0	0	0	0
1998	68522	144129	350258	704359	696636	163552	0	41819	0	41819	0	0
1999	552186	615582	971250	562516	432220	309913	0	0	0	0	0	0
2000	1230000	548539	501592	909489	246728	0	33137	0	0	0	0	0
2001	5453277	7979054	2086730	745694	202234	106854	25274	0	0	0	0	0
2002	434214	1810689	836560	663217	228441	120834	27251	0	0	0	0	0
2003	251708	1033986	6925402	2454125	561162	23750	27601	0	0	0	0	0
2004	289628	2815371	1644419	4184877	1541128	358085	0	67419	0	44433	0	0
2005	67054	94311	1404901	1542991	2758797	479762	0	0	0	0	0	0
2006	183461	1025369	11870042	25289879	9884809	3682080	230187	0	0	0	0	0
2007	234451	78229	858788	3710824	4304320	764071	133764	9815	0	0	0	0
2008	248618	240346	559263	4915850	5972629	2297152	152836	124784	127903	0	0	0
2009	1053638	1243803	2351094	4083530	5578185	2989960	27439	518092	0	0	0	0
2010	26660	141428	642063	122291	489382	488833	41377	94696	0	13918	0	0