Preliminary results from an updated assessment of the squid resource

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Introduction

A Bayesian analysis, to take full account of model uncertainty, was conducted in the past to assess the status of the squid resource *Loligo reynaudii*. The data included in the analysis comprised jig catches (1983-2002), trawl catches (1971-2002), jig CPUE (1985-2002), trawl CPUE (1978-1999), an autumn survey biomass index (1988-1997, 1999) and a spring survey biomass index (1987, 1990-1995, 2001). Twelve models, each assuming a discrete value for *h* (the steepness parameter in the stock-recruit relationship), ranging from 0.40 – 0.95 in units of 0.05, were run and results were integrated over these models.

Subsequent to the presentation of the results from the above-mentioned analysis, additional data have become available and there have also been some modifications made to the input data. Time constraints have precluded conducting a complete re-analysis whereby the results are integrated over the 12 models that were previously considered, where each model assumed a discrete value for steepness *h*. This paper therefore compares results for the assessment model utilizing i) the previous data and ii) the updated data for one of the models considered, namely *h*=0.7. It is therefore important to note that the results presented here are a work in progress and will be subject to a fuller evaluation in the near future.

The Data

Tables 1 – 5 and Figures 1a-j show the previous and updated input data respectively.

Changes of note with respect to the input data are as follows:

- Previously jig catches were derived from the NMLS. The updated data include jig catches sourced from the SABS.
- Previously the jig CPUE index covered the period 1985-2002 and was restricted to those records where 3≤crew≤20. The updated index includes jig CPUE data for the period 1995-2008, restricted to a core set of 19 vessels and those records where 3≤crew≤20.
- Only the survey indices obtained from the “old” trawl gear are utilized.

The model and results

The biomass-based model considered here is detailed in Appendix A. Both process and observation error are taken into account and the likelihood of the data is calculated by assuming the abundance indices to be log-normally distributed about their expected values. A (modified) Beverton-Holt stock-recruit relationship is assumed which makes allowance for jig fishing disturbance impacts on recruitment.

For the Bayesian posterior computations utilizing the previous data a chain of 40 million samples was run, with a thinning of 5000 (to reduce autocorrelations) and a burn-in of 2000 samples. The first 5000 samples (after burn-in) were used to perform stochastic projections 10 years into the future under various constant effort scenarios. Similarly, for the computations utilizing the updated data a chain of 300 million samples was run, with a thinning of 5000 and burn-in of 15000. The first 5000 samples after allowing for burn-in were used to perform stochastic projections ten years into the future under various constant effort scenarios. It should be noted that no rigorous testing for non-convergence has (as yet) been carried out (e.g. diagnostics from the tests of Geweke (1992), Raftery and Lewis (1992) and Heidelberger and Welch (1983)). Instead, plots of the traces of the estimable parameters were simply examined by eye.

It should be noted that for the projections various assumptions are made. These are as follows:

- The proportion of annual jig effort expended in each period is equivalent to the average observed over the last 3 years for which data are available, which is 0.32:0.68 for the Jan-Mar and Apr-Dec periods.
- Future trawl effort is constant and is equivalent to the average standardized effort in the trawl fishery over the last 5 years for which data are available.
- The proportion of annual trawl effort expended in each period is equivalent to the average observed over the last 5 years for which data are available, and is 0.19:0.81 for the Jan-Mar:Apr-Dec .

The parameter estimates at the joint posterior mode for the two datasets (previous and updated) for h=0.7 are shown in Table 6.

The stock-recruitment residuals are shown in Figure 2 and indicate that in recent years there has been above-average recruitment. Fits to the stock-recruitment relationships for the two datasets are shown in Figure 3a-c. Also shown in each plot is the replacement line; this reflects an exact balance between additions from recruitment and losses to mortality, and intersects the stock-recruitment curve at K in the absence of fishing mortality. It is evident from Figure 3c that the improved recruitment (reflected by the updated assessment) has shifted the stock-recruitment curve upwards.

The catch-effort plots obtained from the projections utilizing the previous and updated data are shown in Figures 4 and 5 respectively. Figure 6 compares median curves for both datasets. Also included in Figure 6 is the median curve derived from integrating over results from the 12 discrete values of h from the previous analysis. Sensitivity to the catch-effort curve derived from the updated analysis was tested in terms of: i) repeating the projections with different starting random number seeds, and ii) projecting forward different parts of the chain. The resulting catch-effort curves are shown in Figure 7 and indicate hardly any differences between the respective curves.

It is clear from Figure 6 that the catch-effort curve derived from an assessment of the updated data reflects a markedly more optimistic appraisal improvement compared to those derived from the analyses of the past data. An attempt to determine the cause for this improvement was tested by performing an assessment on data only to 2005. The parameter estimates at the joint posterior mode are shown in Table 6, and the resulting catch-effort curve (compared with those plotted in Figure 6) is shown in Figure 8. This curve lies between the earlier and the most recent ones. The overall improved appraisal seems to stem primarily from the above average recruitment over the last few years.

References

Geweke, J. 1992. Evaluating the Accuracy of Sampling-Based Approaches to the Calculation of Posterior moments. *In* Bayesian Statistics 4. pp169-193. *Edited by* Bernardo, J.M., Berger, J.O., Dawid, A.P., Smith, A.F.M. Oxford University Press, Oxford.

Heidelberger, P., Welch, P.D. 1983. Simulation Run Length Control in the Presence of an Initial Transient. Operations Research. 31: 1109-1144.

Raftery, A.E., Lewis, S.M. 1992. How many Iterations in the Gibbs Sampler? *In* Bayesian Statistics 4. pp763-773. *Edited by* Bernardo, J.M., Berger, J.O., Dawid, A.P., Smith, A.F.M. Oxford University Press, Oxford.

Table 1: Previous and updated jig catches (tons) per period.

	Previous Catches Source: Linefish Database			Updated Catches Source: SABS			Difference SABS-Linefish Database		
Year	**Jan-Mar**	**Apr-Dec**	**Total**	**Jan-Mar**	**Apr-Dec**	**Total**	**Jan-Mar**	**Apr-Dec**	**Total**
1983	85.2	414.8	500						
1984	170.4	829.6	1000						
1985	124.0	2976.0	3100	117	2487	2604	-7	-489	-496
1986	238.0	3162.0	3400	248	3151	3399	10	-11	-1
1987	167.8	2628.2	2796	170	2627	2797	2.2	-1.2	1
1988	193.0	4633.0	4826	213	4614	4827	20	-19	1
1989	2056.3	7735.7	9792	2044	7534	9578	-12.3	-201.7	-214
1990	623.6	2658.4	3282	459	1728	2187	-164.6	-930.4	-1095
1991	201.0	6499.0	6700	149	4330	4479	-52	-2169	-2221
1992	388.2	2199.8	2588	218	1752	1970	-170.2	-447.8	-618
1993	567.7	5740.3	6308	309	6402	6711	-258.7	661.7	403
1994	2512.0	3929.0	6441	2493	4356	6849	-19	427	408
1995	1781.0	5069.0	6850	1735	5578	7313	-46	509	463
1996	1863.0	5037.0	6900	1828	4996	6824	-35	-41	-76
1997	871.7	3036.8	3909	945	2829	3774	73.3	-207.8	-134.5
1998	1438.7	5046.6	6485	1644	4919	6563	205.3	-127.6	77.7
1999	1877.5	5084.3	6962	1662	4973	6635	-215.5	-111.3	-326.8
2000	1110.2	5217.1	6327	1217	4844	6061	106.8	-373.1	266.3
2001	659.2	2442.7	3102	719	2228	2947	59.8	-214.7	154.9
2002	1341.5	5726.6	7068	1819	7795	9614	477.5	2068.4	2545.9
2003				2166	9654	11820			
2004				5028	8233	13261			
2005				2758	6389	9147			
2006				3583	5708	9291			
2007				2044	7394	9438			
2008				3072	6062	9134			

Note: Only total catch was provided from the period 1997-1999 for the SABS series. The split between the two periods for those years was thus derived from interpolation using the average split derived from three years pre-1997 and three years post-1999.

Table 2: Previous and updated trawl catches (tons) per period. Non-italicized catches are what were used in the previous assessment. Catches in italics are updated figures. Foreign catches are included over the period 1971-1992.

Year	Jan-Mar	Apr-Dec
1971	26.64	46.36
1972	186.88	325.12
1973	342.00	595.00
1974	1322.00	2300.00
1975	1331.86	2317.14
1976	769.77	339.23
1977	1205.21	2096.79
1978	1021.20	3967.80
1979	2080.57	3035.43
1980	1006.84	2047.16
1981	1719.16	2036.84
1982	1536.75	2067.25
1983	2304.69	1810.31
1984	586.70	1528.30
1985	1633.12	2053.88
1986	222.88	715.12
1987	238.30	413.70
1988	169.36	651.64
1989	413.20	749.80
1990	290.36	454.64
1991	141.72	351.28
1992	90.22	196.78
1993	50.62	227.38
1994	220.10	266.90
1995	125.43	213.57
1996	155.23	205.77
1997	75.60	161.40
1998	128.37	187.62
1999	90.94	183.72
2000	81.80 (*81.66*)	277.12 (*272.30*)
2001	119.43 (*119.41*)	124.43 (*124.85*)
2002	62.84 (*62.73*)	142.46 (*142.43*)
2003	*76.14*	*261.67*
2004	*123.38*	*267.91*
2005	*94.60*	*279.25*
2006	*134.22*	*223.97*
2007	*126.77*	*369.32*
2008	*169.43*	*353.78*

Table 3: Previous and undated survey indices of abundance (tons). Source: MCM Demersal research survey database. Non-italicized indices are what were used in the previous assessment. Indices in italics are updated figures. Indices in bold were obtained from surveys that used the new trawl gear.

	Autumn Index		**Spring Index**	
	Biomass	**SE**	**Biomass**	**SE**
1986			14478	3152
1987			11992	1704
1988	8957	1316	No survey	
1989	18979	4181	No survey	
1990	8960	1789	13410	1846
1991	14677	3501	23480	4002
1992	13128	1474	10018	1446
1993	22134	3926	14396	2436
1994	22191	5324	15368	2369
1995	23264	3014	14961	1989
1996	26831	2653	No survey	
1997	10021	1023	No survey	
1998	No survey		No survey	
1999	19455	2226	No survey	
2000	*13280*[1]	*1552*[2]	No survey	
2001	*No survey*		10606 (*10583*[2])	1516 (*1535*[3])
2002	*No survey*		No survey	
2003	*22448*	*2937*	***13840***	***1588***
2004	***15496***	***2369***	***18189***	***3826***
2005	***17099***	***2488***	No survey	
2006	*20168*	*2197*	*12960*	*1309*
2007	***21556***	***2436***	***23580***	***3324***
2008	***31379***	***3479***	***20649***	***2835***

Note: The updated assessment includes biomass estimates derived from the use of the old trawl gear only. Nansen and new gear estimates are excluded.

[1] Nansen Survey
[2] Updated calculation

Table 4: Previous and updated jig CPUE indices per period. Units are kg/man/hour for the previous data and kg/man-day for the updated data.

	Previous data		Updated data	
Year	**Jan-Mar**	**Apr-Dec**	**Jan-Mar**	**Apr-Dec**
1985	2.152	5.376		
1986	2.930	2.825		
1987	2.324	3.484		
1988	3.075	3.597		
1989	4.283	4.863		
1990	3.527	2.453		
1991	1.738	3.396		
1992	2.459	2.433		
1993	2.375	3.658		
1994	5.382	2.808		
1995	2.979	2.363	30.478	31.243
1996	2.104	1.889	29.491	25.362
1997	1.213	1.221	15.881	16.242
1998	1.593	2.049	18.215	26.106
1999	3.055	2.576	29.660	25.829
2000	1.490	1.963	19.678	28.157
2001	1.277	1.397	21.360	19.419
2002	2.035	2.891	22.396	30.575
2003			28.436	37.026
2004			45.005	26.742
2005			22.852	21.965
2006			30.478	22.493
2007			23.374	28.238
2008			28.841	37.001

Table 5: Trawl CPUE index (kg/hour) as used in both the previous and updated assessment models (Source: MCM Demersal commercial database).

Year	Jan-Mar	Apr-Dec
1978	13.77	7.46
1979	19.97	7.92
1980	14.52	4.31
1981	17.78	8.12
1982	16.50	4.94
1983	24.10	3.22
1984	8.90	4.02
1985	12.69	3.17
1986	6.20	2.80
1987	5.79	2.11
1988	5.60	3.15
1989	8.81	3.43
1990	6.25	2.07
1991	5.28	2.34
1992	3.84	1.72
1993	3.53	2.09
1994	6.58	2.14
1995	5.20	2.08
1996	5.25	2.10
1997	4.34	1.79
1998	4.83	2.21
1999	5.17	1.84

Note: The trawl CPUE indices have not been updated since the previous assessment. These indices were derived from the application of General Linear Models and a re-analysis of the complete dataset is required since it is not possible to treat the post-2000 data in the same manner as they were treated up to 1999.

Table 6: Parameter estimates at the joint posterior mode, assuming steepness *h*=0.7 utilizing the i) previous data and ii) updated data to 2005 and 2008 respectively.

[redacted]

Figures 1a-j: The input data used in the previous (2006) and updated (2010) assessment models.

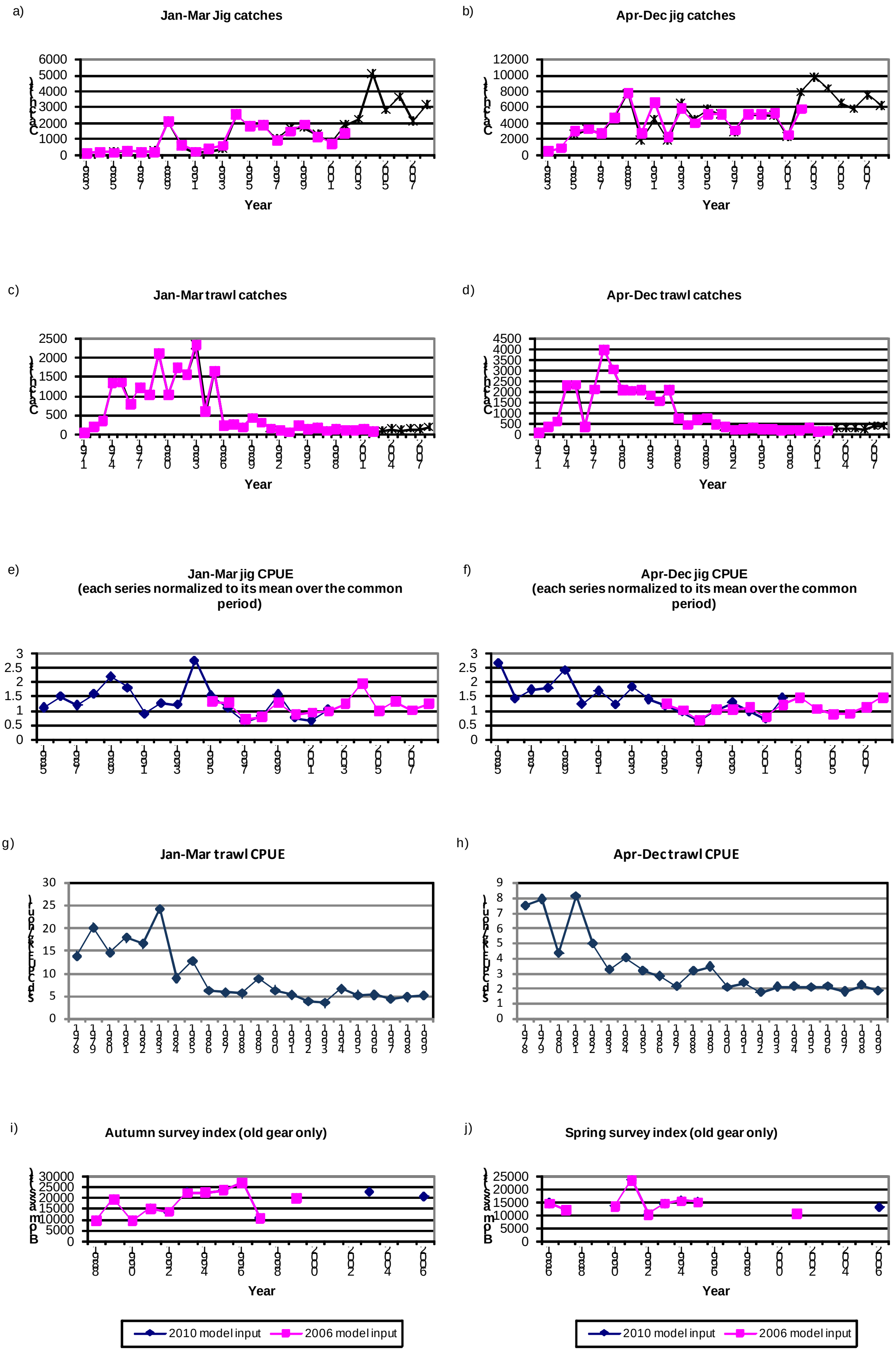
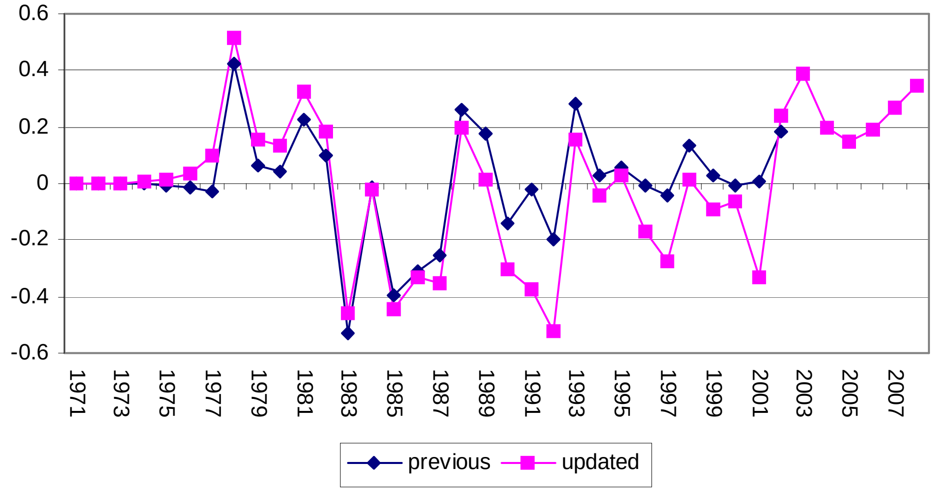


Figure 2: Stock-recruitment residuals estimated from the assessment utilizing i) previous and ii) updated data.



Figures 3a-c: Model predicted stock-recruitment relationships and associated replacement lines from the assessment utilizing previous and updated data. The data points shown are posterior mode estimates from the stock recruitment values each year, and the straight lines through the origin are replacement lines.

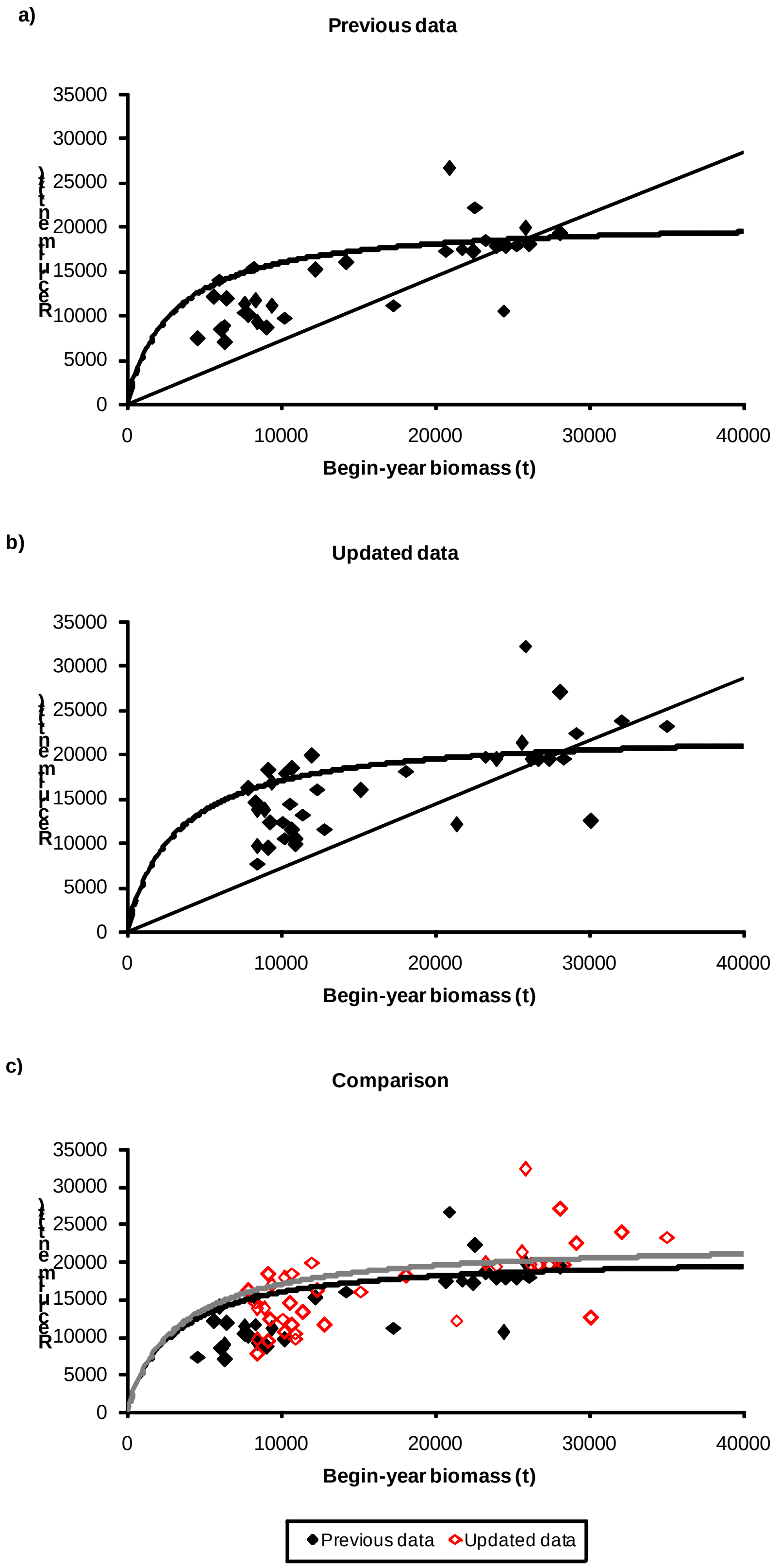


Figure 4: Median average annual catch (tons) with 90% probability intervals for fixed levels of future effort utilizing previous data. Steepness parameter *h* = 0.7. Current effort is 3030 man-hours (indicated by the arrow).

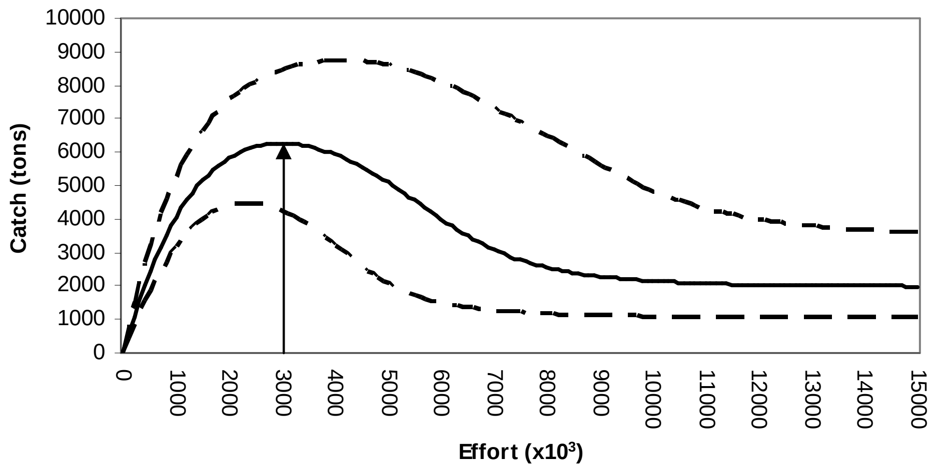


Figure 5: Median average annual catch (tons) with 90% probability intervals for fixed levels of future effort utilizing updated data. Steepness parameter *h* = 0.7. Current effort is 3030 man-hours. Note that effort in terms of man-days was converted to man-hours by multiplying man-day effort by 10.

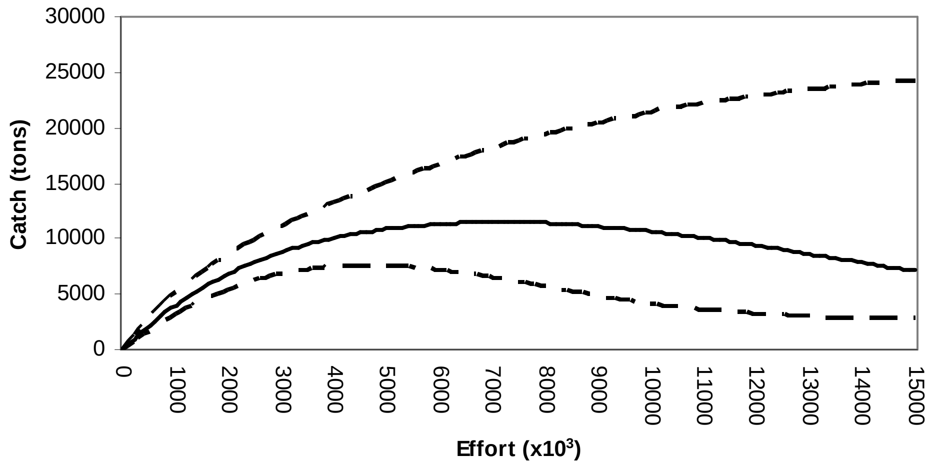


Figure 6: Comparison of median average annual catch (tons) for *h*=0.7 fitting to the i) previous data, ii) updated data and iii) integrating results over *h* ranging from 0.4-0.95. The units of effort are in terms of man-hours.

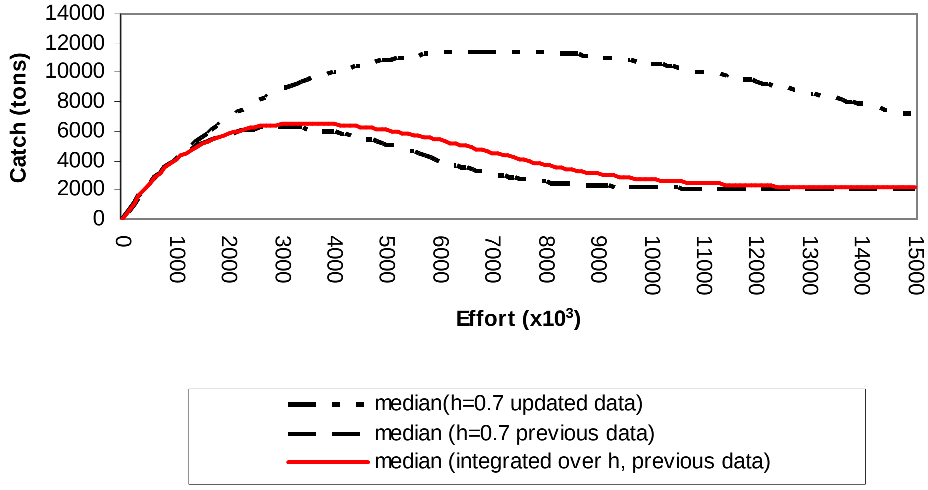


Figure 7: Comparison of median average annual catch (tons) derived from an assessment of the updated data and projecting forward using i) different starting random number seeds and ii) different parts of the chain. Steepness *h*=0.7.

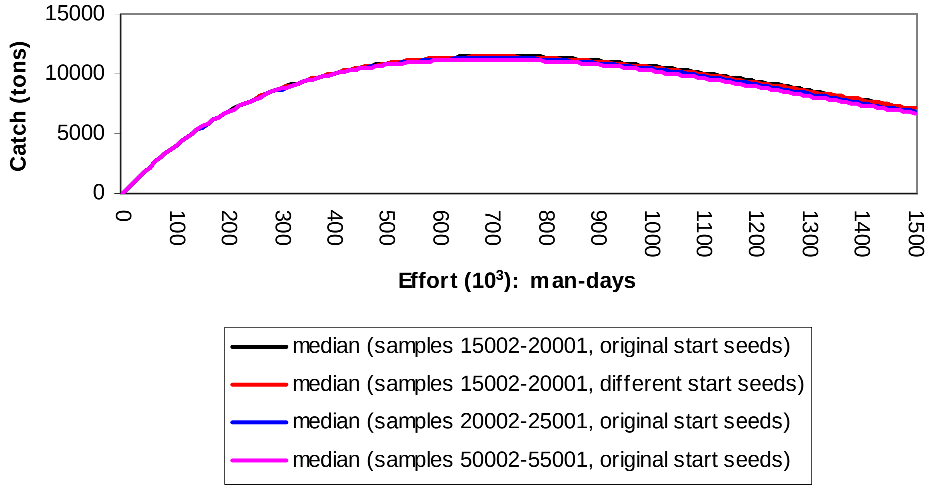
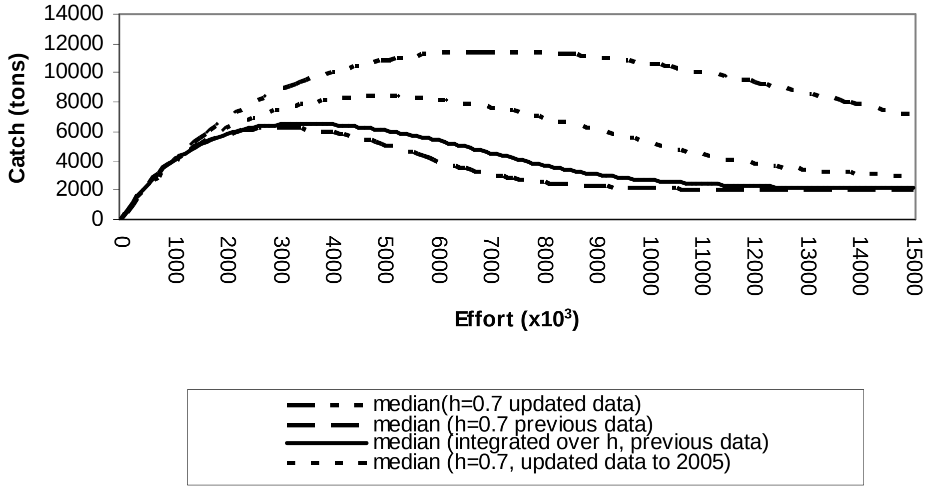


Figure 8: Comparison of median average annual catch (tons) for *h*=0.7 fitting to the i) previous data, ii) updated data, iii) updated data to 2005 and iv) integrating results over *h* ranging from 0.4-0.95. The units of effort are in terms of man-hours.



APPENDIX A: The biomass dynamics model specifications and projection-related catch equations and rules

The population model splits a year into two time periods, January-March and April-December, to better reflect the dynamics of the stock and the two fisheries (jig and trawl) that exploit it (Roel and Butterworth, 2000). Hardly any recruitment takes place in the January – March period, and jig and trawl catches are disproportionately divided between this and the April-December period (Roel and Butterworth, 2000). The biomass time series is estimated by projecting the assumed pristine biomass at the start of the period (B_0) forward given the historic annual catches.

The biomass dynamics for the two periods are given by:

$$B_y = B_y^* e^{-g/4} - C_y^{jig\ J-M} - C_y^{trawl\ J-M} \qquad \text{A.1}$$

$$B_{y+1}^* = B_y e^{-3g/4} + R_y - C_y^{jig\ A-D} - C_y^{trawl\ A-D} \qquad \text{A.2}$$

where B_y^* is the biomass in year y at the start of January,

B_y is the biomass in year y at the start of April,

$C_y^{jig\ J-M}$ is the jig catch taken in year y between January and March,

$C_y^{jig\ A-D}$ is the jig catch taken in year y between April and December,

$C_y^{trawl\ J-M}$ is the trawl catch taken in year y between January and March,

$C_y^{trawl\ A-D}$ is the trawl catch taken in year y between April and December, and

g is a composite parameter that accounts for natural mortality, emigration and growth.

R_y is the recruitment in year y:

$$R_y = \frac{\alpha B_y^* (1-\eta F_y^{jig})}{\beta + B_y^*} e^{(\xi_y - \frac{\sigma_R^2}{2})} \qquad \text{A.3}$$

where:

$$F_y^{jig} = \frac{C_y^{jig\ A-D}}{B_y e^{-3g/4} + R_y} \qquad \text{A.4}$$

η is an estimable parameter and controls the extent to which recruitment is affected by jig fishing mortality. ξ_y is the process error reflecting fluctuation about the expected recruitment for year *y*, drawn from $N(0,\sigma_R^2)$. These residuals are treated as estimable parameters in the model fitting process (σ_R is assumed to be 0.3). The estimated residuals may be used to calculate $\hat{\sigma}_R = \sqrt{\frac{1}{n}\sum_y \xi_y^2}$. The $\frac{\sigma_R^2}{2}$ term is to correct for bias given the skewness of the log-normal distribution.

α and β are stock-recruit relationship parameters. In order to work with estimable parameters that are more meaningful biologically, the stock-recruit relationship is re-parameterized in terms of pre-exploitation equilibrium biomass, *K*, and the "steepness", *h*, of the stock-recruitment relationship ("steepness" being the fraction of pristine recruitment that results when biomass drops to 20% of its pristine level):

$$hR_0 = R(0.2K) \qquad \text{A.5}$$

from which it follows that:

$$h = \frac{0.2(\beta + K)}{\beta + 0.2K} \qquad \text{A.6}$$

and hence:

$$\alpha = \frac{4hR_0}{5h-1} \qquad \text{A.7}$$

and

$$\beta = \frac{K(1-h)}{5h-1} \quad \text{A.8}$$

The likelihood is calculated assuming that the abundance indices are log-normally distributed about their expected values:

$$I_y^i = \hat{I}_y^i e^{\varepsilon_y^i} \quad \text{or} \quad \varepsilon_y^i = \ell n(I_y^i) - \ell n(\hat{I}_y^i) \quad \text{A.9}$$

where

I_y^i is the abundance index for year *y* and series *i*, $\hat{I}_y^i = \hat{q}^i \overline{B}_y$ is the corresponding model estimate, ($\hat{q}^i$ being the catchability coefficient corresponding to series *i* and $\overline{B}_y$ the average biomass during a given period in year *y*), and ε_y^i is the observation error corresponding to series *i* in year *y*.

For the January-March trawl index,

$$\overline{B}_y = \frac{B_y^* + B_y^* e^{-g/4} - C_y^{jig\ J-M} - C_y^{trawl\ J-M}}{2} \quad \text{A.10}$$

For the April-December jig and trawl indices,

$$\overline{B}_y = \frac{B_y + R_y + B_{y+1}^*}{2} \quad \text{A.11}$$

For the autumn survey biomass index,

$$\overline{B}_y = B_y + 0.5R_y \quad \text{A.12}$$

For the spring survey biomass index

$$\overline{B}_y = B_y + R_y \quad \text{A.13}$$

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

$$-\ell n L_i = n\, \ell n \sigma *^i + \frac{1}{2(\sigma *^i)^2} \sum_{y=1}^{n_i} (\varepsilon_y^i)^2 \qquad \text{A.14}$$

where $\hat{\sigma} *^i = \sqrt{(\hat{\sigma}^i)^2 + C^2}$ A.15

$$\hat{\sigma}^i = \sqrt{\frac{1}{n_i} \sum_y (\varepsilon_y^i)^2} \qquad \text{A.16}$$

and C=0.2. The introduction of the C factor is to ensure that no abundance index receives unrealistically high weight in the fitting process.

The contribution of the stock-recruitment residuals to the negative log-likelihood function is given by:

$$-\ell n L = \sum_y [\ell n \sigma_R + \frac{1}{2\sigma_R^2} \xi_y^2] \qquad \text{A.17}$$

This is a penalty term, being the equivalent in a frequentist framework of what would reflect a normal prior in a Bayesian context.

Prior distributions for estimable parameters

The following (uninformative) prior distributions are assumed:

- Pristine recruitment, R_0 ~ U(0,∞)
- Stock-recruitment residuals, $\xi_y \sim N(0, 0.3^2)$
- $g \sim N(1.2, 0.1^2)$
- $\eta \sim (\frac{1-\eta}{0.03+0.97(1-\eta)})/0.9191234596$ (the second denominator being included to normalize the prior)

The derivation of future catches given variability about the catch-effort relationship

The catch-effort relationship $(\frac{C}{E}) = q\overline{B}e^{\varepsilon}$, may be re-arranged to yield $C = qE\overline{B}e^{\varepsilon}$. Substituting equation A.10 for $\overline{B}$ will yield the future catches made in the January-March period for the trawl and jig fisheries respectively. Ignoring the *y* subscripts, these are thus:

$$C^{trawl,J-M} = \frac{q_{trawl,J-M} E_{trawl,J-M} e^{\xi^{trawl,J-M}} B^{*}(1+e^{\frac{-g}{4}})}{(2+q_{jig,J-M} E_{jig,J-M} e^{\xi^{jig,J-M}} + q_{trawl,J-M} E_{trawl,J-M} e^{\xi^{trawl,J-M}})} \quad \text{A.18}$$

$$C^{jig,J-M} = \frac{q_{jig,J-M} E_{jig,J-M} e^{\xi^{jig,J-M}} B^{*}(1+e^{\frac{-g}{4}})}{(2+q_{jig,J-M} E_{jig,J-M} e^{\xi^{jig,J-M}} + q_{trawl,J-M} E_{trawl,J-M} e^{\xi^{trawl,J-M}})} \quad \text{A.19}$$

Similarly, for the second period (April-December), substituting equation A.11 for $\overline{B}$ will yield the future catches made in the trawl and jig fisheries respectively:

$$C^{trawl,A-D} = \frac{q_{trawl,A-D} E_{trawl,A-D} e^{\varepsilon_{trawl,A-D}} \{B(1+e^{\frac{-3g}{4}})+2R\}}{(2+q_{jig,A-D} E_{jig,A-D} e^{\varepsilon_{jig,A-Dy}} + q_{trawl,A-D} E_{trawl,A-D} e^{\varepsilon_{trawl,A-D}})} \quad \text{A.20}$$

$$C^{jig,A-D} = \frac{q_{jig,A-D} E_{jig,A-D} e^{\varepsilon_{jig,A-D}} \{B(1+e^{\frac{-3g}{4}})+2R\}}{(2+q_{jig,A-D} E_{jig,A-D} e^{\varepsilon_{jig,A-Dy}} + q_{trawl,A-D} E_{trawl,A-D} e^{\varepsilon_{trawl,A-D}})} \quad \text{A.21}$$

$\varepsilon_i \sim N(0,(\hat{\sigma}*^{i})^2)$, *i* denoting each index of abundance.

Rules for projections

If the estimated biomass in the second period was less than $0.05(B^{*} \times e^{\frac{-g}{4}})$ then the first period catches were set to $0.95p(B^{*} \times e^{\frac{-g}{4}})$ and the second period biomass to $0.05(B^{*} \times e^{\frac{-g}{4}})$. Similarly, if the estimated biomass in the first period of the following year was less than $0.05(B \times e^{\frac{-3g}{4}} + R)$ then the second period catches from the previous year were set to $0.95p(B \times e^{\frac{-3g}{4}} + R)$ and the first period biomass to $0.05(B \times e^{\frac{-3g}{4}} + R)$. p apportions the catches in the correct ratio for each period and each fishing type.