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Addendum to Annex 12

Government of Japan

INTERNATIONAL
WHALING COMMISSION

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Two aspects of the approach and scenarios presented in Annex 12 of the NEWREP-NP research plan are modified to provide further and improved results.

a) The scenarios considered of step function changes in per capita recruitment (hereafter referred to simply as 'recruitment'), while useful to illustrate the point being addressed, are simpler than would be expected in reality. However such 'realities' are currently available only for Antarctic minke whales from SCAA analyses for those populations, so those Antarctic results have been used here as the basis for some forward simulations for the O stock of North Pacific minke whales.

b) The estimator applied in Annex 12 was simplistic, having only one estimable parameter (K) (aside from future annual recruitment deviations) governing the dynamics overall. Greater flexibility is now introduced.

Methodology

[Note: Certain details of the likelihood function minimised in the fitting process were inadvertently omitted from Annex 12. For a composite self-standing version, the now full corrected version is repeated below, before the details of the new extensions introduced here are provided.]

The model is fitted to estimates of mature female numbers and catch-at-age data to estimate model parameters. Contributions by each of these to the negative of the (penalised) log-likelihood ($-lnL$) are as follows.

Mature female numbers

$$-lnL^{abund} = \sum_j \left\{ \frac{\left(\varepsilon_y^i\right)^2}{2\sigma_y^2} \right\} \tag{3}$$

with

$$\varepsilon_y^i = ln\left(I_y^i\right) - ln\left(\sum_a f_a^{f,j} N_{y,a}^{f,j}\right) \tag{4}$$

where

I_y^i is the estimate of mature female numbers in year y and stock j, and

$$\sigma_y = \begin{cases} 0.01 & \text{for } y = 2000 \text{ (i.e. sufficiently low to force and exact fit to } I_{2000}^i) \\ 0.25 & y \geq 2012 \end{cases}$$

Commercial catches-at-age

The contribution of the catch-at-age data to the negative of the log-likelihood function under the assumption of a multinomial error distribution is given by:

$$-lnL^{CAA} = \sum_{j,y,g,a} -p_{y,a}^{g,j} ln\left(\frac{\hat{p}_{y,a}^{g,j}}{\sum_{a'} \hat{p}_{y,a'}^{g,j}}\right) \tag{5}$$

where

$p_{y,a}^{g,j}$ is the observed number of whale of age a and gender g caught in year y in stock j,

$\hat{p}_{y,a}^{g,j}$ is the model-predicted number of whale of age a and gender g caught in year y in stock j,

where

$$\hat{p}_{y,a}^{g,j} = \sum_{a'} F_y^{g,j} v_{y,a'}^{g,j} r_{a'}^g N_{y,a'}^{g,j} E_{a,a'} \tag{6}$$

with

$E_{a,a}$ being the ageing error matrix (Table A5, Annex 12), and

r_a^g being the age readability at age a for gender g (Table A6, Annex 12).

The standardised residuals are computed as:

$$\varepsilon_{y,a}^{g,j} = \frac{p_{y,a}^{g,j}/\Sigma_{a'} p_{y,a'}^{g,j} - \hat{p}_{y,a}^{g,j}/\Sigma_{a'} \hat{p}_{y,a'}^{g,j}}{\sigma_{y,a}^{g,j}} \tag{7}$$

with

$$\sigma_{y,a}^{g,j} = \frac{p_{y,a}^{g,j} \frac{\hat{p}_{y,a}^{g,j}}{\Sigma_{a'} \hat{p}_{y,a'}^{g,j}} \left(1 - \frac{\hat{p}_{y,a}^{g,j}}{\Sigma_{a'} \hat{p}_{y,a'}^{g,j}}\right)}{\Sigma_{a'} p_{y,a'}^{g,j}} \tag{8}$$

Female births (recruitment) residuals are defined by:

$$b_y^i = B^j N_y^{f,j} \left\{1 + A^j \left[1 - \left(N_y^{f,j}/K^{f,j}\right)^{z^j}\right]\right\} e^{\varphi_y} \tag{9}$$

where φ_y from $N(0,(\sigma_R)^2)$ with $\sigma_R = 0.25$.

with the following penalty added to the negative log-likelihood:

$$pen_{birth} = \Sigma_y \left\{\frac{\left(\varphi_y\right)^2}{2\sigma_R^2}\right\} \tag{10}$$

The standard deviations reported for total numbers are computed as follow, taking account of the estimation bias:

$$\sigma_y^{N_{tot}} = \sqrt{\Sigma_n \left(\hat{N}_y^{tot} - \beta_y - N_y^{tot}\right)^2 / n} \tag{11}$$

with the bias computed as:

$$\beta_y = \left(\hat{N}_y^{tot} - N_y^{tot}\right)/n \tag{12}$$

and similarly for the female births.

New features

The two new scenarios introduced are based on the recruitment variability evident for Antarctic minke (stocks I and P) as estimated in SCAA results for Antarctic minke whales reported to the 2016 annual meeting of the Scientific Committee. The 1970-2010 vector $\boldsymbol{X}$ of moving averages for recruitment variability (renormalized so that the 1970 value is 1, see Table 1 for I and P stocks) is used to project recruitment forward from 2011 (using the 1971 value) onwards, with the 2051 value taken to apply to all years from 2052 onwards. A three-year moving average is used to eliminate some of the estimation error around the real underlying trend; values prior to 1970 are not used as they reflect more model assumptions than being informed by the actual age data. Equation C8 (see Annex 12) for future births is modified:

$$b_y^i = B^j N_y^{f,j} X_y \, e^{\varepsilon_y} \tag{1}$$

Because X_{2051+} for the I stock is high (1.543), this results in a steep increase in total numbers and births in the future, which the existing estimation model with a constant carrying capacity as the only related estimable parameter could not match. To allow for a better fit (to this and also other cases), carrying capacity K is allowed to change (by a limited amount) every 10 projected years, starting in 2012, but staying constant during each of these 10 year periods:

$$K_y = \begin{cases} K_y = K & \text{for } y \leq 2011 \\ K_{y-1} e^{\varepsilon_y} & \text{for } y = 2012, 2022, 2032 \ldots \\ K_{y-1} & \text{for } y \neq 2012, 2022, 2032 \ldots \end{cases} \tag{1}$$

with the following penalty added to the negative log-likelihood:

$$pen_K = \sum_y \left\{ \frac{(\varepsilon_y)^2}{2\sigma_K^2} \right\} \tag{2}$$

with $\sigma_K = 0.1$.

Thus, aside from selectivity-related parameters, the estimable parameters of the revised model are *K*, and the 10-yearly ε_y together with the annual recruitment residuals φ_y.

Results

Results are presented for the baseline run of Annex12 and a series of sensitivities:

Figure 1: Baseline run: A01, MSYR of 1%, 30% drop in (per capita) recruitment after 10 years.

Figure 2: A01, MSYR of 1%, projected recruitment based on stock I recruitment variability.

Figure 3: A01, MSYR of 1%, projected recruitment based on stock P recruitment variability.

Figure 4: A01, MSYR of 1%, 30% increase in recruitment after 10 years.

Figure 5: A01, MSYR of 4%, 30% drop in recruitment after 10 years.

Discussion

Estimation performance for the baseline run (Figure 1) is distinctly improved for the estimator that allows for future changes in *K*. Trends in both total numbers and female births are reflected better, and in particular, given the availability of age data, the change in recruitment is detected earlier and more clearly.

For the standard deviation of the estimates of total numbers, the addition of age data when future changes in *K* are admitted leads to a much bigger improvement over the no-age-data case, especially for the earlier years, compared to a situation where the future value of *K* does not change. However there is a price to pay for the reduction in bias for the estimator which allows these changes, which is reflected by greater variance in later years arising from the estimation of further parameters. For female births the same trends effects are evident, but are of smaller magnitude.

For the other scenarios examined, the bias results are broadly the same when recruitment decreases in future, though estimation performance deteriorates somewhat when this trend is upward.

Table 1: Moving averages of recruitment variability (renormalized so that the values for 1970 for Antarctic minke and for 2011 for the assumed projected values for the North Pacific O stock of minke whales are 1). The Antarctic values correspond to those reported for the I and P stocks of Antarctic minke whales for an MSYR of 1% in analyses presented by Kitakado to the 2016 meeting of the IWC Scientific Committee. The 1970-2010 values from the Antarctic are used in the projections for the 2011-2051 period for the North Pacific, with values being kept constant after 2051.

Year		I-stock (1%)	P-stock (1%)
Antarctic	North Pacific		
1970	2011	1.0000	1.0000
1971	2012	0.9126	0.9964
1972	2013	0.8973	0.9739
1973	2014	0.8204	0.9444
1974	2015	0.6548	0.8903
1975	2016	0.6164	0.7994
1976	2017	0.6395	0.7106
1977	2018	0.5629	0.6338
1978	2019	0.5564	0.5823
1979	2020	0.6362	0.5473
1980	2021	0.6759	0.5475
1981	2022	0.7580	0.6199
1982	2023	0.8806	0.6581
1983	2024	0.9840	0.6786
1984	2025	0.9714	0.6824
1985	2026	1.1005	0.6860
1986	2027	1.0904	0.6196
1987	2028	1.0511	0.5675
1988	2029	0.9935	0.5201
1989	2030	1.0772	0.5039
1990	2031	1.0321	0.4938
1991	2032	1.0715	0.4973
1992	2033	1.0963	0.5278
1993	2034	1.3100	0.5197
1994	2035	1.3289	0.5045
1995	2036	1.4931	0.5570
1996	2037	1.5884	0.6024
1997	2038	1.6565	0.6185
1998	2039	1.6914	0.7480
1999	2040	1.7960	0.8030
2000	2041	1.7229	0.8751
2001	2042	1.7694	0.8129
2002	2043	1.7485	0.7998
2003	2044	1.6526	0.6842
2004	2045	1.5270	0.6529
2005	2046	1.5480	0.5344
2006	2047	1.4261	0.6040
2007	2048	1.5137	0.6128
2008	2049	1.5242	0.6493
2009	2050	1.5664	0.7044
2010	2051+	1.5430	0.7387

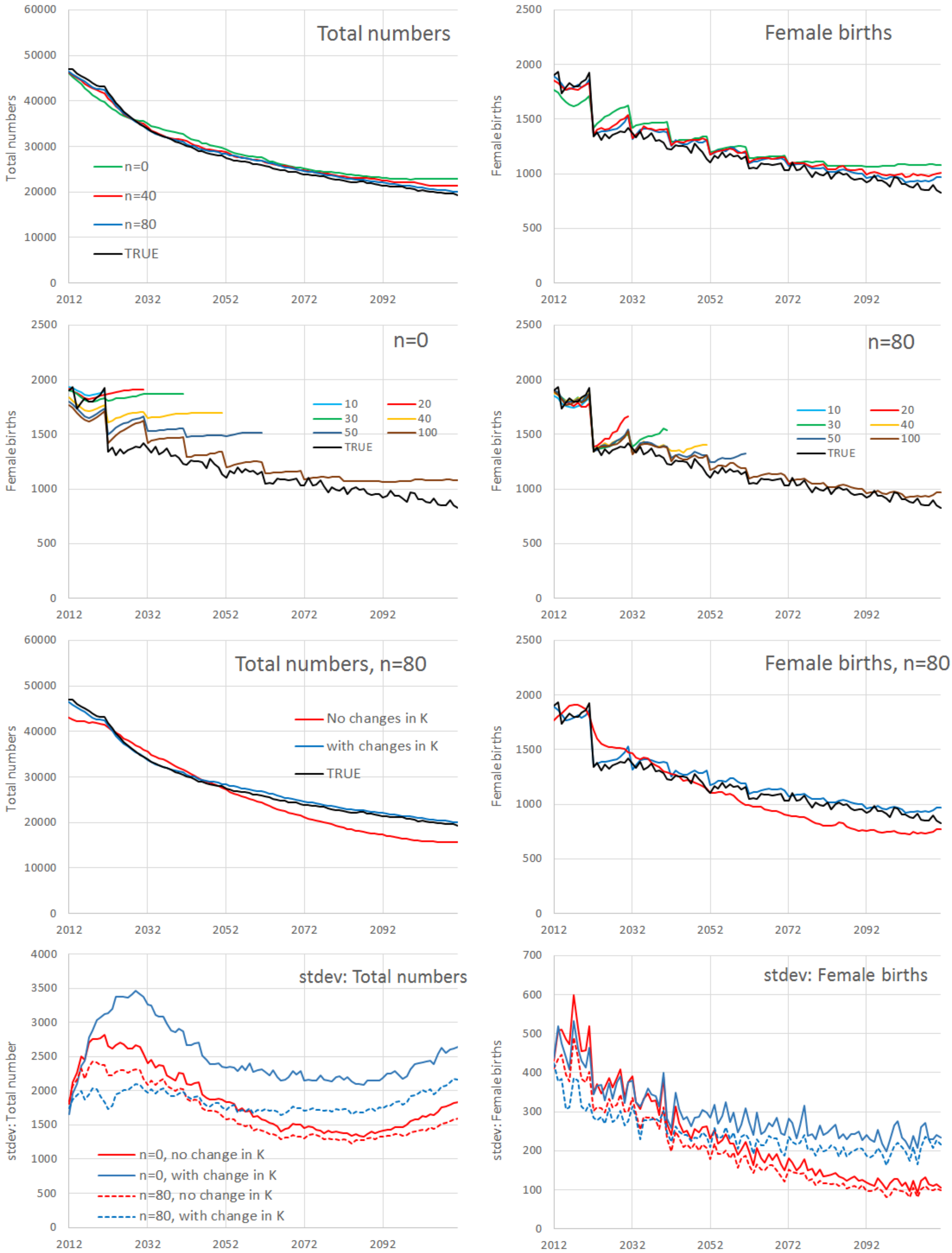

Figure 1: For **A01_1, MSYR 1% recruitments, with a 30% drop in (per capita) recruitment after 10 years**. **Model with estimated change in *K* every 10 years**. First row: Medians for "true" and estimated total numbers and female births for a series of sample sizes. Second row: Medians for "true" and estimated female births for a sample size of 0 (LHS) and 80 (RHS), estimated after 10, 20, 30, 40, 50 and 100 years. Third row: Medians for "true" and estimated total numbers and female births for a sample size of 80 with and without estimated changes in *K*. Fourth row: standard deviations for total numbers (LHS) and female births (RHS) for sample sizes of 0 and 80, with and without estimated changes in *K*.

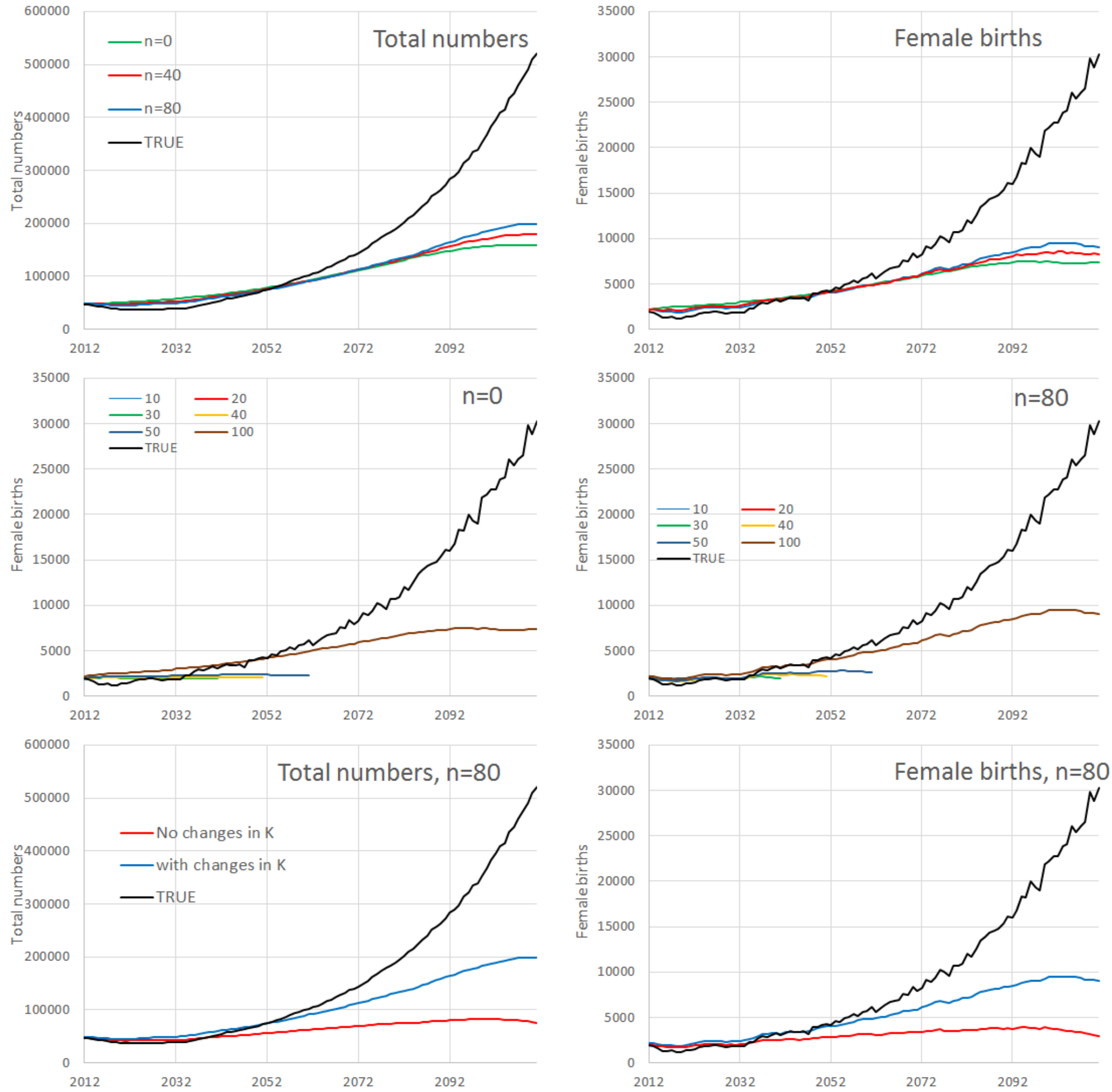

Figure 2: For **A01_1,** for **I stock equivalent MSYR 1% recruitment variations**. **Model with estimated change in *K* every 10 years**. First row: Medians for "true" and estimated total numbers and female births for a series of sample sizes. Second row: Medians for "true" and estimated female births for a sample size of 0 (LHS) and 80 (RHS), estimated after 10, 20, 30, 40, 50 and 100 years. Third row: Medians for "true" and estimated total numbers and female births for a sample size of 80 with and without estimated changes in *K*.

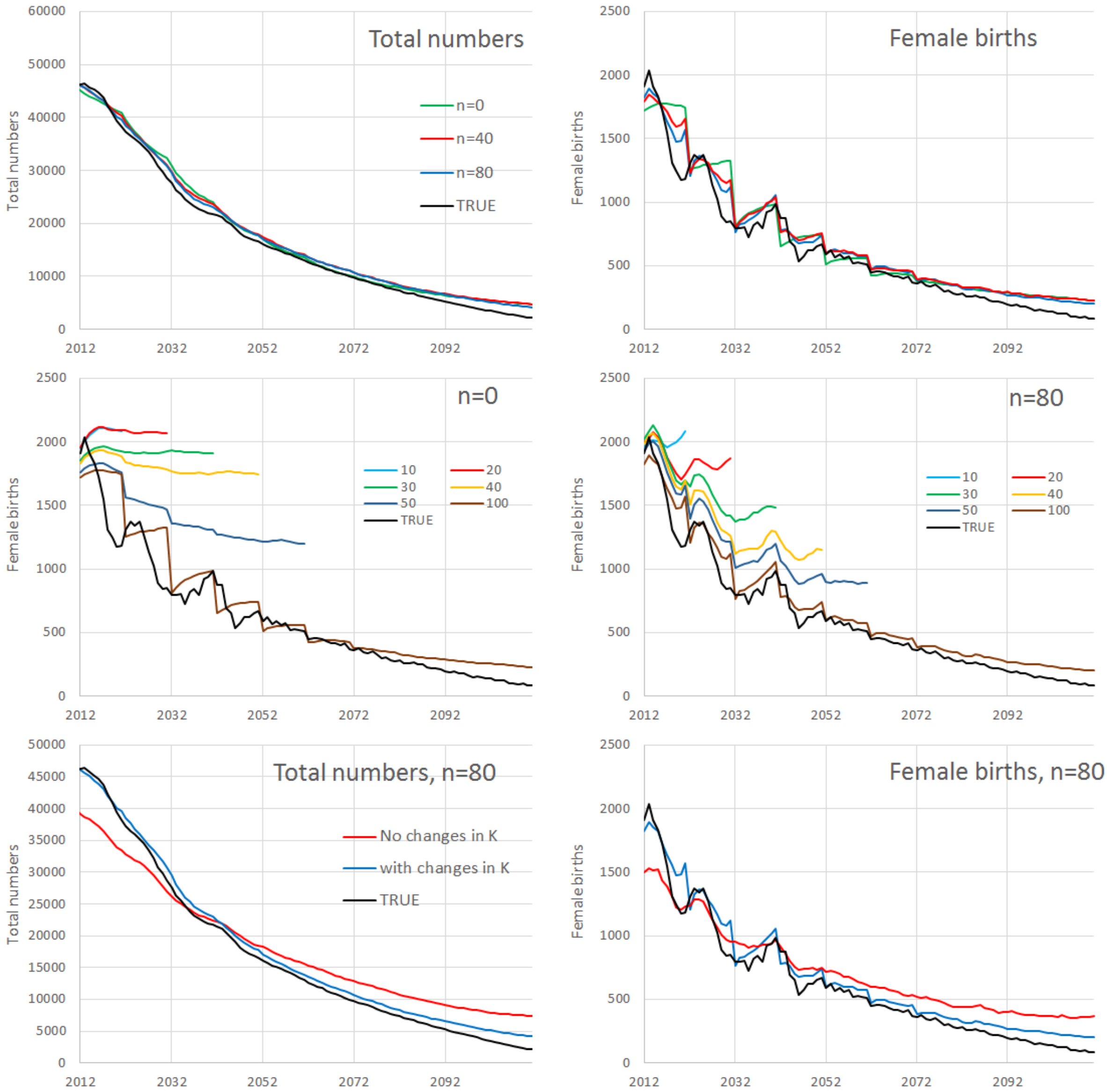

Figure 3: For **A01_1,** for **P stock MSYR 1% equivalent recruitment variations**. **Model with estimated change in *K* every 10 years**. First row: Medians for "true" and estimated total numbers and female births for a series of sample sizes. Second row: Medians for "true" and estimated female births for a sample size of 0 (LHS) and 80 (RHS), estimated after 10, 20, 30, 40, 50 and 100 years. Third row: Medians for "true" and estimated total numbers and female births for a sample size of 80 with and without estimated changes in *K*.

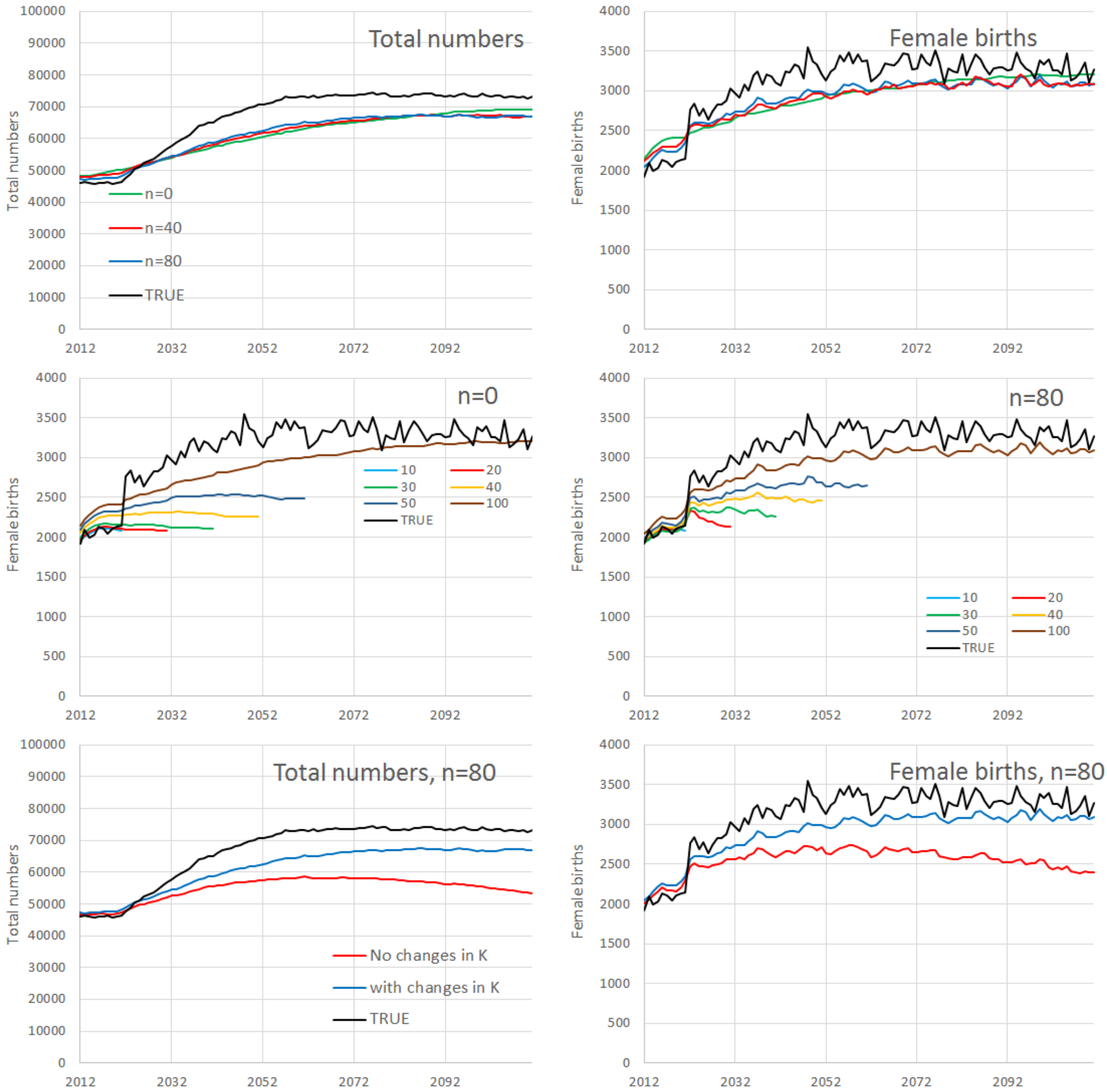

Figure 4: For **A01_1, MSYR 1% recruitments, with a 30% increase in recruitment after 10 years**. **Model with estimated change in *K* every 10 years**. First row: Medians for "true" and estimated total numbers and female births for a series of sample sizes. Second row: Medians for "true" and estimated female births for a sample size of 0 (LHS) and 80 (RHS), estimated after 10, 20, 30, 40, 50 and 100 years. Third row: Medians for "true" and estimated total numbers and female births for a sample size of 80 with and without estimated changes in *K*.

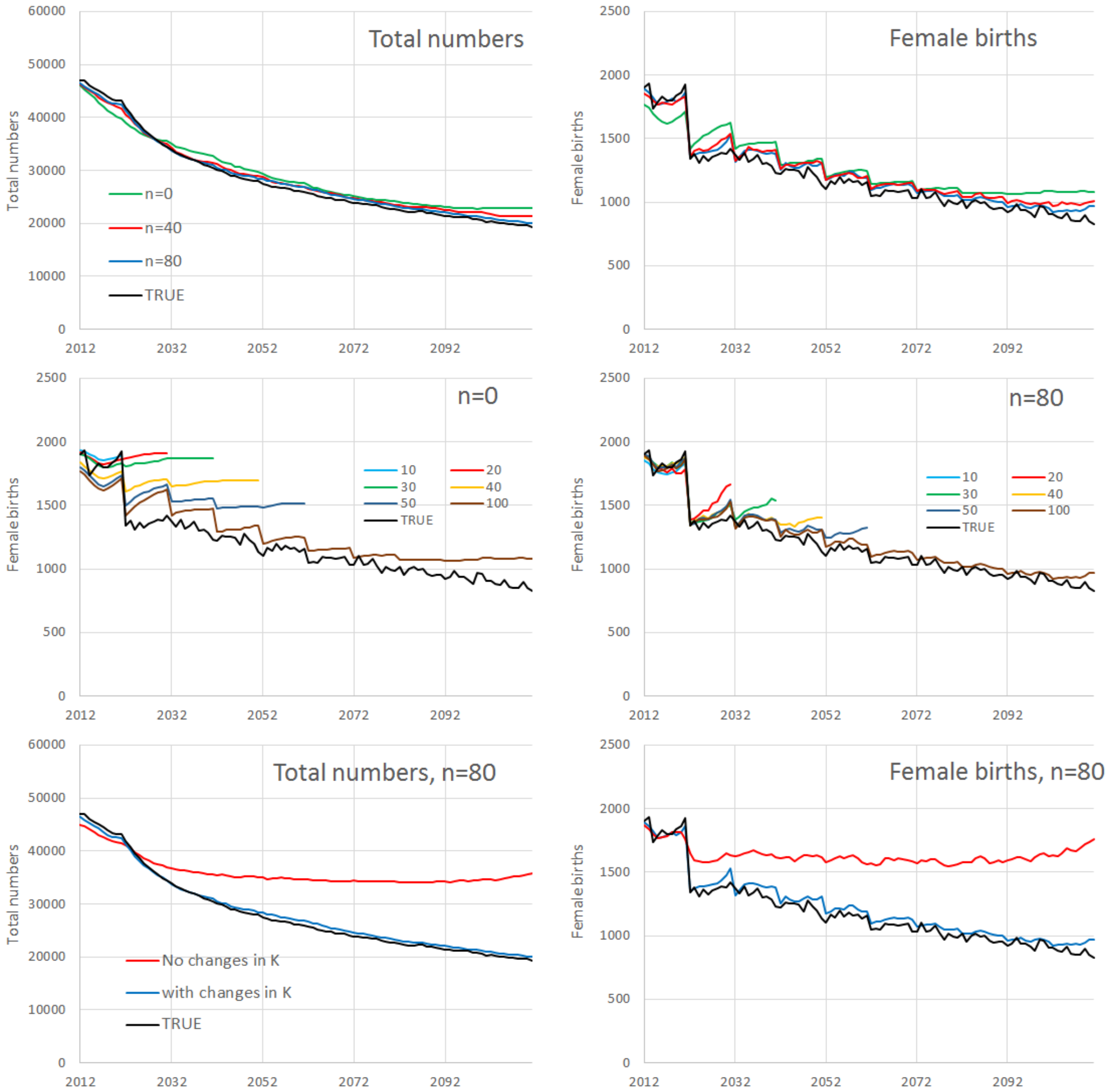

Figure 5: For **A01_4, MSYR 4% recruitments ,with a 30% drop in recruitment after 10 years**. **Model with estimated change in *K* every 10 years**. First row: Medians for "true" and estimated total numbers and female births for a series of sample sizes. Second row: Medians for "true" and estimated female births for a sample size of 0 (LHS) and 80 (RHS), estimated after 10, 20, 30, 40, 50 and 100 years. Third row: Medians for "true" and estimated total numbers and female births for a sample size of 80 with and without estimated changes in *K*.