APPLICATION OF ADAPT-VPA TO VARIOUS STOCK HYPOTHESES FOR THE ANTARCTIC MINKE WHALES DISTRIBUTED THROUGH IWC MANAGEMENT AREAS IIIE TO VIW

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ABSTRACT

This paper focuses primarily on addressing suggestions made during the Ulsan meeting of the Scientific Committee for refinement of the ADAPT-VPA assessments of Antarctic minke whales presented in Mori and Butterworth (2005). The methodology is extended to take account of different selectivities for the Russian and Japanese fleets during the period of commercial whaling, but this has little effect on results. The slopes of catch curves for the research catches have decreased and then stabilised during the course of the JARPA programme. This is indicative of a change in recruitment trends over time, rather than of a very high natural mortality as was amongst the postulates at the time of commercial whaling. ADAPT-VPA assessments are run for the five stock structure hypotheses specified by the Scientific Committee for the minke whales distributed through Areas IIIE to VIW, and for various choices of series of abundance estimates to which to fit the model. These runs generally indicate a trend of increasing recruitment of about 4% pa until the mid-1960s, followed by a trend in total abundance that decreases or is sometimes stable, depending on the abundance estimate series selected for fitting. Results for the I-stock (Areas IIIE+IV+VW) are quite sensitive to this selection, but those for the P-stock (Areas VE+VIW) less so. Estimates of natural mortality M are generally in the 0.06 to 0.09 range, with a tendency to be somewhat higher for the P- compared to the I-stock. Fits of the outputs from the ADAPT-VPA to a stock-recruitment model generally require a carrying capacity for minke whales that first increased and then declined during the last century, and suggest $MSYR_{1+}$ values in the 4-7% range. Possibilities for further work are outlined, including disaggregation of the analysis by sex.

KEYWORD ADAPT-VPA, CATCH-AT-AGE, ANTARCTIC MINKE WHALE

INTRODUCTION

At the 2005 meeting of the Scientific Committee in Ulsan, Mori and Butterworth (2005) presented a paper reporting the results of ADAPT-VPA assessments of Antarctic minke whales based on abundance estimates (from both IDCR/SOWER and JARPA surveys) and catch at age data (both commercial and scientific) for Areas IV and V. The following points were raised in the discussion of this paper at this meeting:

1) The paper needed to be extended to take account of the differences in selectivity patterns between the Japanese and Russian fleets indicated by the analyses of Punt and Polacheck (2005).

2) The paper needed to explore implications of different stock hypotheses that involve extensions of the two area/single stock models to multiple area/single stock models. More specifically it was agreed by the Scientific Committee that the following five stock hypotheses should be explored (see also Figure 1):

    i) Single stock comprising Areas IIIE, IV and VW (so-called “I-stock” in Pastene *et al*. (2005)).

    ii) Single stock comprising Areas VE and VIW (so-called “P-stock” in Pastene *et al*. (2005)).

    iii) Single stock comprising Areas IV and VW.

    iv) Single stock comprising Areas IIIE, IV, VW, VE and VIW.

    v) Two overlapping stocks in the region from Area IIIE through to VIW with Area VW being an area of mixing.

In this paper the results of further work to address these points are reported.

Note that the aim of this paper is not to reach definitive conclusions on trends in total abundance and recruitment for different stock hypothesis scenarios. Rather it is aimed to identify, for example, how sensitive the estimated natural mortality (M) and trajectories are to different sets of abundance estimates (i.e. IDCR/SOWER and JARPA surveys), different weightings of the input catch-at-age data, and various assumptions within the ADAPT-VPA model including those related to stock structure hypotheses.

DATA

Table 1 lists the catch-at-age matrices used for Russian and Japanese catches for Areas IIIE to VIW. These reflect commercial catches from 1971[1] to 1986, and scientific research catches by Japan from 1987 to 2003. The commercial and scientific catch-related information has been developed as described in Butterworth *et al.* (1999), using ageing information kindly provided by R. Zenitani. For the lengths for which there are no age data that year, the 'nearest' length-class is used; in cases where the upper and lower lengths for which there are data are equidistant, the age distributions for those two lengths are averaged.

Table 2 list the survey estimates of abundance for Areas IIIE to VIW that are used in the analyses, together with the associated survey sampling CVs. Estimates from the IDCR/SOWER surveys were kindly provided by T. A. Branch; Appendix 1 provides some details of their development. The estimates from the JARPA surveys listed in Table 2 were kindly provided by T. Hakamada.

Table 3 list the annual proportions of minke whales in Area VW estimated by genetic methods to belong to the I-stock, as cited in Appendix 3 of Government of Japan (2005).

METHODOLOGY

The basic methodology used is same as in Mori and Butterworth (2005), except that some modifications have been introduced to take account of the difference in selectivity pattern for the commercial catches between the Japanese and Russian vessels, and also to take account of the different scenarios specified by the Scientific Committee for stock hypotheses for Antarctic minke whales in the Areas under consideration.

Population model

The basic population dynamics are taken to be governed by the equations:

$$N_{y+1,a+1} = \left(N_{y,a} - C_{y,a}\right)\cdot e^{-M_a} \qquad 1 \le a \le m-1 \tag{1}$$

$$F_{y,a} = C_{y,a} \big/ N_{y,a} \tag{2}$$

$$C_{y,a} = C^R_{y,a} + C^J_{y,a} \quad \text{(thus } F^R_{y,a} = C^R_{y,a} \big/ N_{y,a} \text{ and } F^J_{y,a} = C^J_{y,a} \big/ N_{y,a}\text{)} \tag{3}$$

where

$N_{y,a}$ is the number of minke whales (here of both sexes combined) of age *a* present at the start of year *y*;

$C_{y,a}$ is the number of such whales taken during year *y*, where $C^R_{y,a}$ is the number taken by the Russian vessels[2] and $C^J_{y,a}$ is the number taken by the Japanese vessels;

M_a is the (possibly age-dependent) rate of natural mortality;

$F_{y,a}$ is the proportion of the animals of age *a* present at the start of year *y* that are taken (the "fishing proportion"); and

m is the oldest age considered in the model-fitting process.

Consistent with previous analyses (Butterworth *et al.* 1999, Mori and Butterworth 2005), most of the analyses of this paper take *m*=30. However, results are also shown for alternative choices for *m* up to 45. For analysis purposes, natural mortality M_a is presumed infinite at age 45 and above, so that animals captured above this age are ignored. For choices of *m* < 45, results are projected forward from age *m* to age 45 using equation (1) and known catches, so that all the analyses take account of minke whales up to age 45 irrespective of the choice made for *m*.

A key aspect of the parameterization of the ADAPT-VPA model applied is the assumption that the fishing proportion *F* for both Japanese commercial and scientific takes is separable (in expectation). Different selectivity patterns are assumed for the years of commercial and scientific catches:

$$F^{E,J}_{y,a} = \begin{cases} S^{c,J}_a F^{E,J}_y & y \le 1986 \\ S^s_a F^{E,J}_y & y \ge 1987 \end{cases} \tag{4}$$

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[1] In this paper, the convention is that 1971 refers to the 1971/72 austral summer season.

[2] Only for the commercial period.

where

$S_a^{c,J}$ is the selectivity-at-age for the period of commercial catches by Japanese vessels ($S_m^{c,J}$ =1);

S_a^{s} is the selectivity-at-age for the period of scientific catches (S_m^{s} =1);

$F_y^{E,J}$ is the Japanese fishing proportion (in expectation) for year *y* on age *m* (i.e. the fully selected fishing proportion in cases where $S_a^{c,J/s} \leq 1$ for all *a*); and

$F_{y,a}^{E,J}$ is the expected Japanese fishing proportion on animals of age *a* for year *y*; this differs from the actual proportion $F_{y,a}^{J}$ because actual catches $C_{y,a}^{J}$ differ from their expectations ($C_{y,a}^{E,J} = F_{y,a}^{E,J} N_{y,a}$) as a result of sampling variability (at least).

Note that the Russian commercial catches $C_{y,a}^{R}$ enter the computations only through equation (1); these are calculated by application of Japanese age-length keys to length distribution data for the Russian commercial catches.

The primary estimable parameters of the model are effectively:

- The natural mortality M_a (usually taken to be age-independent).
- The oldest-age numbers-at-age $N_{y,m}$.
- The most-recent-year numbers-at-age $N_{n,a}$, where *n* is the last year for which data are available.

Given values for these parameters, the complete numbers-at-age matrix ($N_{y,a}$) for the population can then be computed by use of equation (1).

The Likelihood function

For single Area assessments, the likelihood function has three components related to the IDCR/SOWER estimates of abundance, the JARPA estimates of abundance and the catch-at-age data. The contribution of the first of these to the negative of the log likelihood (ignoring constants) is given by:

$$-\ln L_1 = \sum_y \frac{1}{2\sigma_y^2}\left(\ln N_y^{obs} - \ln \hat{N}_y\right)^2 \tag{5}$$

where

N_y^{obs} is the abundance estimate for year *y*;

σ_y is the standard error of the logarithm of N_y^{obs}, which is approximated by $\sqrt{CV_y{}^2 + CV_{add}{}^2}$;

CV_y is the survey sampling CV estimated for N_y^{obs} ;

CV_{add} is an additional CV to reflect the fact that survey sampling error is not the only factor contributing to the difference between N_y^{obs} and $\hat{N}_y$; and

$\hat{N}_y$ is the model estimate of 1+ abundance for year *y*[3], given by:

$$\hat{N}_y = \sum_{a=1}^{45} \hat{N}_{y,a} \qquad (6).$$

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[3] Note that for earlier years, the model does not provide abundance estimates of the older of the age groups in this summation. The basis for adjusting estimates shown later in Figures is explained in Mori and Butterworth (2005).

The contribution of the JARPA estimates of abundance is similar, except that these are treated as indices of relative abundance:

$$-\ln L_2 = \sum_y \frac{1}{2\sigma_y^2}\left(\ln N_y^{obs} - \ln\left(q\hat{N}_y\right)\right)^2 \tag{7}$$

where

q is the multiplicative bias associated with abundance estimates from JARPA compared to those from IDCR/SOWER, and is given by its maximum likelihood estimate:

$$\ln\hat{q} = \left\{\sum_y \frac{\ln\left(N_y^{obs}/\hat{N}_y\right)}{\sigma_y^2}\right\} \Bigg/ \left\{\sum_y 1/\sigma_y^2\right\} \qquad (8).$$

Finally the contributions of the commercial and the scientific catch-at-age data are given by:

$$-\ln L_3^{c,J} = -\lambda^{c,J} \sum_{y=1971}^{1986}\sum_{a=16}^{m} C_{y,a}^{J,*} \ln \hat{p}_{y,a}^{J} \tag{9}$$

$$-\ln L_3^{s} = -\lambda^{s} \sum_{y=1987}^{2003}\sum_{a=1}^{m} C_{y,a}^{*} \ln \hat{\rho}_{y,a} \tag{10}$$

where

$C_{y,a}^{J,*}$ is the effective number of animals of age *a* caught by Japan during year *y*, computed as $C_{y,a}^{J}\, C_y^{J,*} \big/ C_y^{J}$;

C_y^J is the total Japanese catch in numbers during year *y*;

$C_y^{J,*}$ is the number of animals actually aged by Japan for year *y*, which also are taken into account in the L_3 calculation for that year (i.e. with ages from 16 to *m* for the commercial, and from 1 to *m* for the scientific catches);

$\lambda^{c,J/s}$ is a factor to account for overdispersion in the Japanese commercial/scientific catch-at-age distribution (underdispersion is not admitted, so that the constraint $0 < \lambda \le 1$ is applied); and

$\hat{\rho}_{y,a}$ is the model-estimate of the expected proportion of the catch in year *y* that consists of animals of age *a*, which from equation (4) is given by:

$$\hat{\rho}_{y,a} = \begin{cases} S_a^{J,c} N_{y,a} \Big/ \sum_{a'=16}^{m} S_{a'}^{J,c} N_{y,a'} & y \le 1986 \\ S_a^{s} N_{y,a} \Big/ \sum_{a'=1}^{m} S_{a'}^{s} N_{y,a'} & y \ge 1987 \end{cases} \qquad (11).$$

A time-invariant commercial selectivity-at-age pattern ($S_a^{J,c}$) is assumed to apply only above age 15, on the basis of arguments by Sakuramoto and Tanaka (1985) that the pattern below this age varies appreciably from year to year. The overdispersion factors λ are estimated by iterative application of the formula:

$$\lambda^{c/s} = \sum_y 1 \Bigg/ \sum_y \left\{ \frac{C_y^{J,*} \sum_a \left(\rho_{y,a} - \hat{\rho}_{y,a}\right)^2}{\sum_a \hat{\rho}_{y,a}\left(1 - \hat{\rho}_{y,a}\right)} \right\} \tag{12}$$

where the years and ages in the summations are as adopted above for $L_3^{c,J}$ and L_3^{s}, and $\rho_{y,a}$ is the observed proportion of the catch during year *y* which consists of animals of age *a*:

$$\rho_{y,a} = \begin{cases} C_{y,a}^{J,*} \Big/ \sum_{a'=16}^{m} C_{y,a'}^{J,*} & y \le 1986 \\ C_{y,a}^{*} \Big/ \sum_{a'=1}^{m} C_{y,a'}^{*} & y \ge 1987 \end{cases} \tag{13}$$

When two areas (e.g. Area IV and Area V) are assessed in combination, allowance needs to be made for the fact that the survey estimates now apply to only a portion of the combined areas minke whale abundance. If the proportion in Area IV in year y is p_y^1, and hence the proportion in Area V that year is $p_y^2 = (1 - p_y^1)$, then equation (5) is adjusted to read:

$$-\ln L_1 = \sum_{y(IV)} \frac{1}{2\sigma_y^2}\left[\ln N_y^{obs} - \ln\left(p_y^1 \hat{N}_y\right)\right]^2 + \sum_{y(V)} \frac{1}{2\sigma_y^2}\left[\ln N_y^{obs} - \ln\left\{\left(1 - p_y^1\right)\hat{N}_y\right\}\right]^2 \tag{14}$$

where the two summations are over years with IDCR/SOWER surveys in Area IV and in Area V respectively.

Equation (7) for the contribution from the JARPA survey abundance estimates is adjusted similarly. The p_y^i s become estimable parameters of the model, though note that in years with a survey in both Areas, the same p_y^i is taken to apply (as any difference arising from the JARPA and IDCR/SOWER surveys taking place at slightly different times during the season seems likely to be relatively small).

When three areas (e.g. Areas IIIE, IV and VW) are assessed in combination, equation (14) becomes:

$$-\ln L_1 = \sum_{y(IV)} \frac{1}{2\sigma_y^2}\left[\ln N_y^{obs} - \ln\left(p_y^1 \hat{N}_y\right)\right]^2 + \sum_{y(IIIE)} \frac{1}{2\sigma_y^2}\left[\ln N_y^{obs} - \ln\left\{p_y^2 \hat{N}_y\right\}\right]^2 + \sum_{y(VW)} \frac{1}{2\sigma_y^2}\left[\ln N_y^{obs} - \ln\left\{\left(1 - p_y^1 - p_y^2\right)\hat{N}_y\right\}\right]^2 \tag{15}$$

where the proportion in Area IV in year y is p_y^1, the proportion in Area IIIE that year is p_y^2, and the proportion in Area VW that year is $p_y^3 = \left(1 - p_y^1 - p_y^2\right)$. Equation (15) is extended naturally when four or more areas are assessed in combination.

Allowing the p_y^i s to be unconstrained (other than $0 \le p_y^i \le 1$) would lead to an under-determined model, in the sense that the p_y^i s could then adjust for the model to match each abundance estimate exactly (except in years with surveys in more than one area). On the other hand, setting $p_y^i = p^i$ (constant) seems unrealistic as it does not allow for changes in the distribution of whales between the areas from year to year. Accordingly for the case of two areas assessed in combination, the p_y^i s have been assumed to follow a beta distribution with parameters u^1 and u^2:

$$\mathbf{p}_y = \left(p_y^1, p_y^2\right) \sim \mathrm{B}\left(u^1, u^2\right) \tag{16}$$

with the approximate estimation approach then used (within the MLE context applied) being the addition of the following further contribution to the negative of the log likelihood:

$$-\ln L_4 = Y \cdot \left\{\ln\Gamma\left(u^1\right) + \ln\Gamma\left(u^2\right) - \ln\Gamma\left(u^1 + u^2\right)\right\} + \sum_y \left[-\left(u^1 - 1\right)\ln p_y^1 - \left(u^2 - 1\right)\ln\left(1 - p_y^1\right)\right] \tag{17}$$

where the summation extends over the years for which there is a survey in at least one of the two areas and Y is the total number of corresponding years.

When more than two areas are assessed in combination, the p_y^i s have been assumed to follow a Dirichlet distribution. For example, when three areas are assessed in combination:

$$\mathbf{p_y} \sim Dirichlet\left(u^1, u^2, u^3\right) \tag{18}$$

with the addition of the following further contribution to the negative of the log likelihood:

$$-\ln L_4 = Y \cdot \left\{\ln\Gamma\left(u^1\right) + \ln\Gamma\left(u^2\right) + \ln\Gamma\left(u^3\right) - \ln\Gamma\left(u^1 + u^2 + u^3\right)\right\} + \sum_y \left[-\left(u^1 - 1\right)\ln p_y^1 - \left(u^2 - 1\right)\ln p_y^2 - \left(u^3 - 1\right)\ln\left(1 - p_y^1 - p_y^2\right)\right] \tag{19}$$

Again this equation is extended naturally when four or more areas are assessed in combination.

In implementation, the parameters:

$$E\left[p^i\right]=\frac{u^i}{u^{tot}} \tag{20}$$

$$\text{where } u^{tot}=\sum_{i=1}^{n} u^i$$

which are the average proportions of the combined abundance to be found in each area *i* of a total of *n* areas considered are treated as estimable parameters of the model, except that the parameter u^1 is fixed externally, with different values being chosen to achieve different levels of inter-annual variability (in terms of CVs) of p^i :

$$CV\left(p^i\right)=\sqrt{\frac{u^{tot}-u^i}{u^i\left(u^{tot}+1\right)}} \tag{21}.$$

In summary, the estimable parameters in the model are as follows (see also Butterworth *et al.* (1999) for further details):

(i) the age-independent (or dependent) natural mortality, *M*;

(ii) numbers-at-age for all ages for the final year considered;

(iii) numbers-at-age for the maximum age considered in the likelihood for every year;

(iv) one selectivity-at-age (for ages 16-21) for the period of commercial catches;

(v) two selectivities-at-age (for ages 1 and 2-6) for the period of scientific catches;

(vi) u^i s, which define the beta (or Dirichlet) distributions (except that u^1 is input); and

(vii) p_y^i s which are the proportions of the whales in area *i* in year *y*.

Specifications of the scenarios considered

The initial scenario considered in this paper is similar to that analysed in Mori and Butterworth (2005) for the combination of Areas IV and V, except that the selectivity for age 1 for the scientific catches (S_1^s) is estimated separately. This is because investigative analyses which involved estimating scientific selectivities for ages of 6 years and less by different age-class groupings suggested that estimating S_1^s separately and setting $S_2^S=S_3^S=\cdots=S_6^S$ would result in a statistically better fit of the model to the data in terms of the Akaike Information Criterion (AIC)[4] (see Table 8.3a in Mori 2005). In addition to this initial scenario, the five stock hypotheses scenarios listed in the Introduction section are investigated.

For the fifth stock hypothesis scenario (two overlapping stocks in the region from Area IIIE through to VIW with Area VW being an area of mixing), the following equation related to the relative abundances of the two stocks in Area VW was added to the overall likelihood:

$$-\ln L_5=\frac{1}{2}\cdot\sum_y\left[\frac{\left(r_y-\frac{\hat{N}_y^{VW\_I}}{\left(\hat{N}_y^{VW\_I}+\hat{N}_y^{VW\_P}\right)}\right)^2}{SD\left(r_y\right)^2}\right] \tag{22}$$

where r_y is the genetically estimated proportion of animals in Area VW in year *y* that are from the I-stock, as listed in Table 3,

$\hat{N}_y^{VW\_I}$ is the model predicted number of minke whales from I-stock in Area VW in year *y*, and

$\hat{N}_y^{VW\_P}$ is the model predicted number of minke whales from P-stock in Area VW in year *y*,

where the summation extends over the years for which there is a genetic estimate of the proportion of whales in Area VW that belong to the I-stock.

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[4] AIC penalizes the goodness of fit by adding 2 to twice the negative log-likelihood for every estimable parameter added to the model.

The catches in Area VW for this scenario were allocated between the I-stock and P-stock in proportion to their relative abundances in that Area for the year in question. This was achieved by iteration[5].

Estimation of selectivity trends with age

The average selectivity trends with age for the Japanese and Russian commercial catches and the scientific catches are of interest. To estimate these the following function, for which the results from the ADAPT-VPA were used as inputs, was minimised:

$$SS^{J/R/s} = \sum_{y,a} \left(C_{y,a}^{J/R/s} - \hat{C}_{y,a}^{J/R/s} \right)^2 \tag{23}$$

where

$$\hat{C}_{y,a}^{J/R/s} = S_a^{J/R/s} \cdot \hat{N}_{y,a} \cdot F_y^{J/R/s} \tag{24}$$

$$S_a^{J/R} = \begin{cases} \gamma + \delta \cdot a & 1 \le a \le 4 \\ \alpha + \beta \cdot a & 4 \le a \le 16 \\ 1 & 16 \le a \le 30 \\ e^{-\omega \cdot (a-30)} & a \ge 30 \end{cases} \tag{25}$$

$$S_a^{s} = \begin{cases} S_a^{s1} & a = 1 \\ S_a^{s2} & 2 \le a \le 6 \\ 1 & 7 \le a \le 30 \\ e^{-\omega \cdot (a-30)} & a \ge 30 \end{cases} \tag{26}$$

Reference case and sensitivity tests

Since earlier analyses have used all the available abundance estimates and catch-at-age data for most of their results, this paper continues that practice for a “Reference case”[6]. Runs are also conducted omitting some of these data, but in the interests of keeping to a manageable set of results, sensitivities are not run for every possible combination of such factors, but rather for convenience results are shown for modifications to the Reference case which generally alter only one factor at a time.

The sensitivity tests run for each of the stock hypothesis scenarios involve some or all of the following:

1. Maximum age *m* considered in the likelihood is 45 rather than 30.
2. Either the JARPA or the IDCR/SOWER estimates of abundance are omitted.
3. Either the scientific or the commercial period catch-at-age information is downweighted by a multiplicative factor of 0.1 in the log-likelihood.
4. The relationship between natural mortality and age is taken to be piecewise linear as defined below (this function is kept of the same form as that used by Punt and Polacheck (2005) to make comparisons of results between the two methods easier):

$$M_a = \begin{cases} M_0 & \text{if } a \le a_1 \\ M_1 + (M_1 - M_0) \cdot \dfrac{(a - a_1)}{(a_2 - a_1)} & \text{if } a_1 \le a < a_2 \\ M_1 & \text{if } a_2 \le a \le a_3 \\ M_1 + (M_x - M_1) \cdot \dfrac{(a - a_3)}{(a_4 - a_3)} & \text{if } a_3 \le a < a_4 \\ M_x & \text{if } a \ge a_4 \end{cases} \tag{27}$$

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[5] Iteration commenced assuming a 50:50 split of the catch from Area VW between I-stock and P-stock whales. For the Reference case (see below) for this scenario (with *m*=30), results after the first iteration hardly differed. Since conducting these iterations is extremely time-consuming, they were have not yet been undertaken for the sensitivities for this scenario reported later, which thus are all based on a 50:50 catch split. In view of the results for the Reference case, it is not anticipated that this approximation introduces any appreciable error.

[6] This term is used deliberately, rather than to call this a "Base Case", to reflect that there is no intention to imply that the selection of data used for this Reference case is necessarily the best.

where M_0 is the rate of natural mortality for animals aged a_1 and younger,

M_1 is the rate of natural mortality for animals aged between a_2 and a_3, and

M_x is the rate of natural mortality for animals aged between a_4 and older.

Computations here take a_1=3, a_2=10, a_3=30, and a_4=35, as implemented in Punt and Polacheck (2005).

Stock-recruitment model

A stock-recruitment model of the Pella-Tomlinson form described in Butterworth and Mori (2005) is fit to the recruitment and adult female abundance estimates from the ADAPT-VPA for stock hypothesis scenario i) ("Areas IIIE+IV+VW; so-called I-stock") and ii) ("Areas VE+VIW; so-called P-stock") to investigate the extent of changes in carrying capacity[7] and to estimate the *MSYR* for these stocks.

The "adult" (reproductive) population is taken to be:

$$N_y^A = \sum_{a=7}^{45} N_{y,a} \tag{28}$$

and the number of adult females $N_y^f = 0.5 \cdot N_y^A$, i.e. an age at first-parturition of 7 is assumed.

Recruitment is assumed to follow a Pella-Tomlinson form:

$$N_{y+1,1} = \lambda \cdot N_y^f \left[1 + A \left\{ 1 - \left(\frac{N_y^f}{K_y^f} \right)^z \right\} \right] \tag{29}$$

where

$N_{y,1}$ is the recruitment (1-year-olds) in year *y*,

λ is the combined pregnancy and first year survival rate when the population is at carrying capacity,

N_y^f is the number of adult (past the age of first parturition) females, taken to be given by $0.5\sum_{a=7}^{45} N_{y,a} = 0.5N_y^A$ (i.e. equal numbers of males and females are assumed),

A is the resilience parameter (related to *MSYR*),

K_y^f is the carrying capacity for adult females, which may change over time, and

z is the degree of compensation parameter, which is set here at 2.39, as conventional in the Scientific Committee.

When $N^f = K^f$, the recruitment must equal the number of 1+ whales dying annually as a result of natural mortality, i.e:

$$\lambda \cdot K_y^f = K^{1+} \left(1 - e^{-M} \right) \tag{30}$$

(ignoring for simplicity the small correction that accounts for an assumed infinite natural morality from age 45).

Further, expressions for unexploited equilibrium numbers at age values yield:

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[7] Here carrying capacity is defined as the carrying capacity for the number of adult female minke whales.

$$\frac{K^{1+}}{K^{f}}=\frac{\sum_{a=1}^{45}e^{-M\cdot a}}{0.5\cdot\sum_{a=7}^{45}e^{-M\cdot a}}=\mu \tag{31}$$

where μ can be computed given the value of *M*.

Thus equation (29) can be rewritten:

$$N_{y+1,1}=\mu\left(1-e^{-M}\right)N_y^f\left[1+A\left\{1-\left(\frac{N_y^f}{K_y^f}\right)^{2.39}\right\}\right] \tag{32}$$

The unknown parameters of this model are *A* and the parameters describing *K* and its temporal variation. These are then estimated by minimizing:

$$SS=\sum_y\left(\ln\left(N_{y,1}^{obs}\right)-\ln\left(N_{y,1}^{model}\right)\right)^2 \tag{33}$$

where

$N_{y,1}^{obs}$ is the "observed" recruitment for year *y* from the result of the ADAPT-VPA assessment, and

$N_{y,1}^{model}$ is the recruitment for year *y* predicted by the model of equation (32), which is implemented under the assumption that $N_{1930}^f=K_{1930}^f$.

The following functional form for K_y^f considered is as in Butterworth and Mori (2005):

$$K_y^f=\begin{cases}K_1^f & y\le y_1\\ K_1^f+\frac{\left(K_2^f-K_1^f\right)}{\left(y_2-y_1\right)^{\gamma}}\left(y-y_1\right)^{\gamma} & y_1+1\le y\le y_2\\ K_2^f+\frac{\left(K_3^f-K_2^f\right)}{\left(y_3-y_2\right)}\left(y-y_2\right) & y_2+1\le y\le y_3\\ K_3^f & y_3+1\le y\end{cases} \tag{34}$$

with the following choices made for the "change" years: $y_1=1930$, $y_2=1960$ and $y_3=2000$,

where K_y^f is set to be

$$K_y^f\to K_y^f\cdot e^{\varepsilon_y} \tag{35}$$

where the ε_y are estimable parameters which are constrained to change somewhat smoothly over time under the assumption:

$$\eta_y \text{ from } N\left(0,\sigma^2\right) \text{ where } \eta_y=\varepsilon_{y+1}-\varepsilon_y \tag{36}$$

which was implemented by adding the following term to the right hand side of equation (33):

$$\sum_{y=1930}^{2002}\left(\varepsilon_{y+1}-\varepsilon_y\right)^2\Big/2\sigma^2 \tag{37}$$

Note that estimation of the resilence parameter *A* when this model is fitted to ADAPT-VPA output allows $MSYR_{1+}$ and $MSYL_{mat}$ to be computed, the latter generally being close to 0.6.

RESULTS

Before considering detailed results from the ADAPT-VPA model runs, it is of interest to step back to consider the JARPA scientific catch-at-age data in isolation and their implications. Some 17 years ago, Butterworth and Punt (1990), in considering the potential information content of such (then future) data, argued that these could resolve the debate at that time about whether the steep slope of the catch curve (a plot of the log of the catch numbers-at-age against age) from the period of commercial whaling reflected a high natural mortality rate (or decreasing selectivity at age), or rather an increasing trend in past recruitments. They pointed out that the first of these hypotheses suggested that the slope of the catch curve for research whaling would remain unchanged over time, whereas the second suggested that it would decrease and then stabilise at a lower value.

Figure 2 shows annual estimates of those catch curve slopes from the catch-at-age research whaling data. The Chapman-Robson estimator; $Z(y)=\ln(1+1/\bar{a}(y))$ (Chapman and Robson 1960) was used to provide these slope estimates. Only ages of 7 and above were considered ($\bar{a}(y)$ being the amount by which the average age of such animals in year *y* exceeds 7), given indications (see below) that the selectivity of these catches falls for ages below 7. For all of the three regions for which results are shown, there is evidence of consistency with the second rather than the first hypothesis above, given that the slope estimates stabilise after the mid-1990s at values lower by about 0.02 than at the time when research whaling commenced. More accurately stated, these data are hardly consistent with very high natural mortality, but rather favour hypotheses that the trend in minke whale recruitment has decreased in the later decades of the last century (note that this covers a variety of possibilities, from an increase that continues but at a lesser rate, to an increase followed by a decrease, and to a decrease that continues at greater magnitude).

There are two key features underlying the ADAPT-VPA results that follow. First, given that attempts to estimate *q* (the relative bias of the JARPA compared to the IDCR abundance estimates) generally provide results close to and not significantly different from 1, the assumption that $q=1$ has been incorporated into the Reference cases. Secondly the parameter u^1 of the beta/Dirichlet distributions (see equations 20 and 21) was chosen so that the standard deviation of the standardised[8] residuals for the survey estimates of abundance was (about) 1. In other words, variability in the distribution of the population between the Areas over which it ranges is assumed to account for all variance in excess of the survey sampling CV, so that CV_{add} (see following equation 5) is effectively set to zero. It should further be noted that $-\ln L$ values shown for the ADAPT-VPA results are not always comparable within sensitivities for a particular scenario (e.g. when age-dependence in *M* is estimated compared to the Reference case with an age-invariant *M*, because the catch-at-age overdispersion parameters (the λ's – see equations 9 and 10) are re-estimated for each fit.

1. Estimation of the selectivity forms separately for the commercial catches by Japanese and Soviet vessels

Mori and Butterworth (2005) indicated dissatisfaction with their assumptions for the manner in which selectivity dropped below 1 for ages of less than 7 for the scientific catches, because of poor fits to the catch-at-age proportions for age 1. This was investigated further in Mori (2005), where the form reflected in equation (26) was found to provide an improved fit consistent with these data. Figure 3 shows the resultant plots for total abundance and recruitment estimated by Mori (2005) for that initial scenario (Areas IV and V combined) for the Reference case with $m=30$. Those results do not distinguish the Russian and Japanese commercial catch-at-age data. Figure 3 also shows corresponding results for the approach of this paper which now distinguishes those data to allow for differing Russian and Japanese commercial selectivities. It is evident that the introduction of this distinction makes only a slight difference to the results.

Figure 4 shows the selectivity at age for the commercial and scientific periods normalized so that $S^{C}_{16-30}=1$, $S^{S}_{7-30}=1$ as estimated using equations (23) to (26) for this initial scenario. For the commercial period, selectivities for the Japanese and Russian vessels are estimated separately. This plot indicates that the selectivities for the Russian commercial catches were marginally higher than those for the Japanese commercial catches especially for older ages. This could be due to Russian vessels being able to operate closer to the pack-ice, where older animals may be preferentially aggregated.

2. ADAPT-VPA assessments results

These results are listed in Table 4, which includes both Reference case and sensitivity results for all five stock structure hypotheses. Figures 5-13 plot a number of these results, which in most cases are shown for fits to both the IDCR and JARPA abundance estimates, and also to only one of these two sets of data. The CI's shown in these plots are Hessian-based. In some cases the recruitment for the first year for which this can be estimated is relatively high; this reflects the fact that only a single datum coupled to an assumption relating terminal fishing mortalities (see Butterworth *et al.* 1999 equation 7) determines such estimates, so that these are not particularly reliable (and generally manifest large CIs).

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[8] The standardisation is in terms of the sampling CV estimated for the survey in question.

The I-stock (Areas IIIE+IV+VW) is considered first with Figure 5 showing fits to abundance (1+) survey results followed by the associated recruitment trend estimates. Note that in years for which there are no survey estimates, the plots for abundance are based on setting the proportions of the total abundance in each Area equal to their expectations. Figure 6 compares the Reference case with certain key sensitivities, while Figure 7 contrasts estimates of *M* and associated 95% CIs for such options.

Figures 8-10 show results for the P-stock (Areas VE+VIW) similarly to those for the I-stock in Figures 5-7. Total population and recruitment estimates are shown in Figures 11-13 for the respective scenarios of combining Areas IV+VW, all Areas from IIIE to VIW as a single stock, and the P-stock and I-stock for a situation where the P-stock extends to the west to mix with the I-stock in Area VW.

3. **Fits of the stock-recruitment model**

Table 5 and Figures 14 and 15 give results for the fits of the stock-recruitment model, with the associated trends in carrying capacity K^f, for the I-stock and P-stock scenarios. These are shown both for the Reference cases and for some sensitivities.

DISCUSSION

Most results show the same broad features: a total abundance trend that increases until about 1970, and then declines, with recruitment trends that show a similar pattern, though reaching their maxima about 5 years sooner. There are, however, a number of instances where the abundance stabilises or even increases after 1970. These estimated trends in abundance are very sensitive to the estimate of natural mortality *M*, which in turn depends on the time-series of abundance estimates selected for input to the model fitting process. The higher *M*, the less the initial increase and the greater the later decline. The lower *M*, the greater the initial increase and the less the decline or the more likely stabilisation or increase over recent years.

In the case of the I-stock (Areas IIIE+IV+VW) (see Figures 5-7), results are sensitive to whether the IDCR or the JARPA estimates of abundance are used as inputs. The former leads to a high estimate of *M*=0.10, together with recruitment that is initially flat but then decreases, as does the total population. In contrast, the use of JARPA abundances estimates only sees *M* estimated at the lower bound of 0.03 imposed by the software, coupled to a recent total abundance trend that is essentially flat. The high IDCR abundance from the 1978/79 cruise is strongly influential on the results. For the Reference case which includes both abundance estimate series, results are intermediate, with *M* estimated at 0.06. Importantly in this case, all the abundance estimate data remain consistent with the model (see Figure 5a), which interprets the fluctuations in the survey estimates as to some fairly large part a consequence of inter-annual changes in distribution of the I-stock abundances across the three Areas considered.

For the P-stock (Areas VE+VIW), there is much greater consistency in results in relation to whether the IDCR, JARPA or both sets of abundance estimates are used (see Figure 9 in particular). *M* estimates are somewhat higher, but span a narrower range of 0.07 to 0.09. Figure 10 shows that *M* is estimated reasonably precisely if both sets of abundance estimates are input.

Results when Areas IV+VW are considered a single stock are similar to those for the I-stock scenario. When all Areas from IIIE to VIW are treated as one stock results for the initial rate of increase in recruitment and *M* are intermediate between those for the I- and the P-stocks.

For the case where two stocks mix in Area VW, the estimation allowed for stock-specific estimates of *M* (given the differing results for the I- and P-stocks above), though results in Table 4 suggest this not to have been necessary. Compared to results for the two stocks in isolation, those for the I-stock are similar, but the P-stock shows a lower *M* estimate and corresponding higher initial rate of increase in recruitment.

Allowing for age-dependence in *M* has little effect on results. There is a general trend of increased values of *M* for lower ages.

To summarise the results overall, most show an initial increase in recruitment estimates of about 4% pa, followed either by a stock decline (typically at between about 1-3% pa over recent decades) or sometimes stabilisation. These latter trends are very sensitive to the estimate of natural mortality *M*, which in turn depends on the time-series of abundance estimates selected for input to the model fitting process. If all available data are considered, the estimates of *M* are reasonably precise, with 95% CIs corresponding to about +-0.02; thus the estimate for the P-stock, though higher than that for the I-stock, is not significantly so.

For the fits to the stock-recruitment model, carrying capacity generally shows an increase to about 1960, followed by a decline. The case of the I-stock fitted to the JARPA abundance estimates alone, does however reflect a difference, with no subsequent decrease in carrying capacity after the initial increase. As might be expected from the ADAPT-VPA results, there are greater differences between the results of sensitivities for the I-stock than for the P-stock. Estimates of $MSYR_{1+}$ range from 4% to 7%.

FURTHER WORK

Due to the restricted time available and already large numbers of sensitivity tests conducted, it was not possible to further explore sensitivities to selectivity function form assumptions. Furthermore, it is important to conduct the analyses distinguishing the male and female components of these minke whale populations since selectivity of the whales during the commercial period seems likely to be different between males and females especially for higher latitudes probably due to different distribution patterns for the sexes, especially near the ice-edge. It is planned to pursue these aspects in future analyses.

In addition, the uncertainties reported in the stock-recruitment model and hence the estimated values of the K_y^f do not incorporate uncertainties of the output from the ADAPT-VPA model. Thus the confidence intervals reported for K_y^f may be negatively biased. This could be resolved by estimating the K_y^f within the ADAPT-VPA model by including a stock-recruitment function within the ADAPT-VPA formulation. Such an approach would have the added advantage of avoiding the need for the procedure to “adjust” total population size estimates for earlier years, and will be considered in future analyses.

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APPENDIX 1

IDCR/SOWER ESTIMATES FOR SH MINKE CATCH-AT-AGE ANALYSES

T.A. BRANCH

Preliminary minke whale abundance estimates calculated from the IDCR/SOWER cruise data for use in catch-at-age analyses are as follows.

Area	Longitudinal coverage	Surveys	N	CV	Year to which applies (as per convention of this paper)
IIIE	35°-70°E	1979/80	80,551	0.381	1979/80 (1979)
IIIE		1987/88	37,428	0.426	1987/88 (1987)
IIIE		1992/93+1994/95	20,465	0.238	1994/95 (1994)
IV	70°-130°E	1978/79	130,333	0.178	1978/79 (1978)
IV		1988/89	84,815	0.288	1988/89 (1988)
IV		1994/95+1998/99	13,409	0.279	1998/99 (1998)
VW	130°-165°E	1980/81	78,093	0.470	1980/81 (1980)
VW		1985/86	77,194	0.249	1985/86 (1985)
VW		1991/92	10,055	0.282	1991/92 (1991)
VW		2001/02 + 2002/03	46,169	0.174	2001/02 (2001)
VE	165°E-170°W	1980/81	164,993	0.328	1980/81 (1980)
VE		1985/86	172,828	0.147	1985/86 (1985)
VE		1991/92	187,266	0.210	1991/92 (1991)
VE		2002/03 + 2003/04	100,658	0.170	2003/04 (2003)
VIW	170°-145°W	1983/84	67,161	0.227	1983/84 (1983)
VIW		1990/91	8,394	0.294	1990/91 (1990)
VIW		1995/96	33,323	0.230	1995/96 (1995)

Note that these (sub-)Areas correspond to the regions covered by the JARPA surveys (see, for example, ICR document JA/J05/JR3 on the ICR website); in particular the VW/VE division here is at 165°E to correspond to an hypothesised stock division line based on genetic analyses and agreed for use in these catch-at-age analyses.

The "Year to which applies" is the year to which the estimate should be assumed to apply in the model fitting process. In cases where two survey seasons are involved, it is that one of the two during which the greater part of the (sub-)Area was covered.

The author is developing a major update of the full set of IDCR/SOWER abundance estimates for minke whales in terms of the "standard methodology" for presentation at the 2006 IWC SC meeting. So that the catch-at-age analyses can proceed in the meantime, the estimates above have not awaited the completion of this task, which will take some time yet. Instead these estimates have been based on the approach of Branch (2005), and have the following broad features/specifications:

- Estimates are standardised to IO mode assuming $g(0)=1$, and combining modes using inverse variance weighting with a constant inter-mode calibration factor R=0.826 (CV=0.089) from Branch and Butterworth (2001).
- Where the survey stratum spans a sub-Area boundary, the abundance estimate required has been obtained by pro-rating proportional to longitudinal coverage.

- Pro-rating was conducted prior to combining survey modes.
- For the first two circumpolar cruises for which coverage did not always extend as far north as 60ºS, the estimates given include extrapolation for this unsurveyed area by assuming a density equal to that in the corresponding northern stratum of the survey.
- There is little by way of common factors used to generate the estimates listed, so that any additions required can adequately assume independence for computing the associated CV.

Final updated estimates may differ somewhat from those given above, *inter alia* because the actual sightings will be correctly allocated to the sub-Areas prior to abundance estimation instead of dividing strata estimates in proportion to their longitudinal coverage. These final estimates may be available before the 2006 SC meeting, but it is conceivable that the SC meeting itself might decide to change some of the associated assumptions for recomputation during that meeting.

It is recommended that all pre-SC catch-at-age computations be conducted using the estimates above to ensure comparability, rather than be repeated should updates become available before the SC meeting. The changes associated with such updates are hardly likely to influence conclusions drawn about the relative appropriateness of alternative catch-at-age model options. Final runs of preferred analysis choices with inputs of updated abundance estimates could be run during the SC meeting (or later) to provide “final” results.

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Table 1 Catch at age matrices by Area and by nation. For economy of space, ages have been grouped by 3, so that age 5 (for example) combines ages 4-6. Note that 1971 reflects the 1971/72 season.

Area IIIE – Japan

Year/Age	2	5	8	11	14	17	20	23	26	29	32	35	38	41	44	47	50	54+
1971	3	11	18	96	18	26	85	28	19	52	0	0	0	0	0	0	0	0
1972	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
1973	78	133	131	124	135	118	115	80	74	32	25	12	8	3	6	0	0	3
1974	53	159	251	236	191	131	87	65	42	27	14	8	4	0	0	1	0	0
1975	20	123	133	169	132	122	139	80	46	10	17	14	6	4	0	0	4	0
1976	23	120	148	207	202	206	158	121	55	60	29	34	7	7	6	0	2	0
1977	5	60	86	98	194	143	105	105	79	53	16	30	16	11	5	2	0	5
1978	34	102	207	245	273	238	176	134	63	50	31	22	7	10	3	4	0	1
1979	20	63	63	70	74	93	58	70	68	50	24	17	14	8	5	3	3	1
1980	19	75	102	103	90	70	64	42	24	15	6	7	0	1	0	1	0	0
1981	10	36	33	47	38	34	23	17	6	2	7	4	0	0	1	0	0	0
1982	0	0	0	0	0	0	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	0	0	0	0	0	0
1984	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
1985	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
1986	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
1987	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
1988	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
1989	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
1990	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
1991	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
1992	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
1993	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
1994	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
1995	12	12	6	13	13	9	1	11	5	8	8	6	1	2	0	0	0	0
1996	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
1997	20	10	20	15	5	11	7	7	5	5	2	2	2	0	1	0	0	0
1998	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
1999	24	28	11	12	12	8	3	4	3	3	1	1	0	0	0	0	0	0
2000	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
2001	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
2002	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
2003	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0

Area IIIE – USSR

Year/Age	2	5	8	11	14	17	20	23	26	29	32	35	38	41	44	47	50	54+
1971	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
1972	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
1973	12	25	18	17	16	11	14	8	5	4	2	3	1	0	1	0	0	1
1974	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
1975	10	85	133	187	170	143	168	100	60	13	23	25	8	3	0	0	3	0
1976	16	67	134	271	253	226	186	130	62	69	27	29	7	8	3	0	2	0
1977	6	72	97	84	150	109	60	79	39	32	14	17	18	3	4	1	0	3
1978	5	35	81	119	123	105	87	67	30	25	15	13	3	5	0	2	0	0
1979	9	57	94	74	71	97	61	72	87	55	27	25	20	12	8	2	3	2
1980	9	54	97	97	99	81	76	46	26	17	7	8	0	1	0	1	0	0
1981	11	86	151	216	121	93	64	51	33	6	18	14	0	0	2	0	0	0
1982	0	0	0	0	0	0	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	0	0	0	0	0	0
1984	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
1985	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
1986	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0

Table 1. Cont.

Area IV – Japan

Year/Age	2	5	8	11	14	17	20	23	26	29	32	35	38	41	44	47	50	54+
1971	123	255	313	309	351	318	283	234	146	95	98	45	30	25	3	7	13	8
1972	128	374	401	306	272	216	143	123	50	39	18	13	3	4	0	0	0	0
1973	261	246	278	305	230	185	170	96	92	76	39	26	26	2	6	5	0	0
1974	38	88	138	132	116	108	57	58	49	27	15	6	4	1	2	0	2	0
1975	6	77	63	80	62	63	32	17	11	11	5	3	5	0	0	0	0	0
1976	15	126	112	193	188	122	73	68	18	13	12	0	2	4	0	0	0	4
1977	25	31	62	61	77	82	41	35	33	17	8	3	5	0	0	2	0	0
1978	34	91	137	172	153	116	92	66	39	22	19	11	1	1	1	0	3	0
1979	84	164	152	184	199	214	148	109	78	62	47	28	20	15	11	11	3	3
1980	77	148	153	137	150	135	116	94	53	48	21	25	13	8	9	4	2	1
1981	65	155	195	221	211	239	171	119	106	59	41	15	17	5	4	3	1	0
1982	55	85	92	134	115	160	138	93	65	37	13	11	6	10	1	3	1	0
1983	89	152	140	167	138	145	93	85	48	36	7	4	2	3	0	0	0	0
1984	18	38	44	65	73	60	63	52	39	21	13	8	0	2	2	0	0	0
1985	8	19	36	50	70	79	79	68	42	29	13	10	11	1	0	1	0	0
1986	12	22	42	53	68	88	65	56	43	29	13	11	7	3	2	1	0	0
1987	28	44	33	24	29	25	31	14	17	13	3	6	2	1	0	0	0	0
1988	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
1989	35	53	48	23	15	36	30	19	27	14	8	7	5	5	1	0	0	0
1990	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
1991	39	39	39	24	20	21	18	12	16	20	15	9	7	2	2	2	1	1
1992	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
1993	58	47	46	42	22	25	16	11	17	12	14	7	6	1	1	2	1	1
1994	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
1995	34	34	34	50	26	17	20	18	27	12	12	17	7	5	3	7	3	4
1996	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
1997	87	36	36	27	20	19	14	17	10	10	15	13	9	2	5	6	0	2
1998	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1
1999	40	42	37	32	28	28	22	17	10	15	17	11	13	8	7	3	0	0
2000	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1
2001	42	39	38	21	26	24	27	17	14	18	9	16	14	10	8	3	1	2
2002	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
2003	39	30	45	21	28	30	23	16	12	13	18	8	18	7	8	8	4	1

Area IV – USSR

Year/Age	2	5	8	11	14	17	20	23	26	29	32	35	38	41	44	47	50	54+
1971	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
1972	224	563	537	347	254	195	133	114	37	31	22	8	1	2	0	0	0	0
1973	342	348	388	364	273	210	197	109	99	81	40	23	35	2	7	8	0	0
1974	3	65	173	234	199	229	122	142	109	55	26	12	11	2	2	0	6	0
1975	10	49	87	88	67	78	26	14	10	10	4	2	4	0	0	0	0	0
1976	7	57	80	140	137	83	55	52	11	7	10	0	3	4	0	0	0	4
1977	31	37	72	75	74	83	31	25	30	12	6	1	5	0	0	0	0	0
1978	4	24	49	79	73	58	44	33	19	11	9	5	1	1	0	0	1	0
1979	2	18	35	43	44	49	39	28	21	17	11	8	6	3	3	3	1	0
1980	26	92	144	154	167	153	126	109	63	56	25	30	19	10	11	2	4	2
1981	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
1982	23	63	90	137	106	162	134	95	63	41	9	9	5	8	2	1	1	0
1983	31	113	137	168	131	144	93	83	45	30	7	2	1	4	0	0	0	0
1984	31	70	96	135	143	125	127	94	72	40	29	17	0	3	5	0	0	0
1985	11	42	88	91	131	138	113	117	58	44	17	17	24	1	0	1	0	0
1986	20	51	87	111	142	149	114	99	70	47	20	16	14	8	2	1	0	0

Table 1. Cont.

Area VW – Japan

Year/Age	2	5	8	11	14	17	20	23	26	29	32	35	38	41	44	47	50	54+
1971	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
1972	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
1973	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
1974	17	46	90	92	87	58	47	32	20	2	7	2	0	0	0	0	0	0
1975	10	63	56	70	66	58	44	24	17	6	4	4	0	0	0	0	0	0
1976	7	101	112	143	180	152	95	64	53	48	19	18	4	6	6	0	0	2
1977	11	51	106	116	82	81	66	36	31	18	6	1	2	3	3	0	0	0
1978	7	13	22	30	27	29	7	15	11	7	1	3	0	1	0	0	0	0
1979	36	56	83	71	75	58	34	21	17	20	6	8	3	4	3	1	0	0
1980	4	40	41	46	57	53	38	44	36	30	10	14	12	6	4	1	0	0
1981	13	82	95	108	165	182	151	102	102	50	31	30	14	9	7	4	2	0
1982	26	114	216	258	281	295	244	175	117	72	48	16	17	12	3	1	0	1
1983	79	170	151	203	244	189	124	93	61	27	22	12	3	3	1	0	0	0
1984	24	67	88	104	112	173	128	84	56	39	13	14	5	1	1	0	0	0
1985	33	52	66	102	128	182	128	105	101	44	31	24	6	7	1	2	1	0
1986	4	32	48	102	117	141	171	125	118	80	31	25	5	6	1	2	1	3
1987	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
1988	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
1989	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
1990	3	31	18	13	19	16	18	19	13	9	8	6	7	2	2	3	0	0
1991	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
1992	10	13	29	23	20	10	13	16	23	10	16	13	7	1	2	1	0	0
1993	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
1994	20	10	15	12	16	12	7	9	10	7	1	8	3	0	0	0	0	0
1995	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
1996	10	15	8	15	17	4	9	6	8	7	6	7	6	4	2	0	4	0
1997	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
1998	13	9	28	12	19	18	11	8	17	13	5	14	6	5	1	2	0	0
1999	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
2000	9	17	6	10	13	16	4	11	11	5	11	11	9	0	2	2	0	3
2001	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
2002	3	7	9	11	10	12	13	7	10	5	5	0	4	0	0	1	1	1
2003	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0

Area VW – USSR

Year/Age	2	5	8	11	14	17	20	23	26	29	32	35	38	41	44	47	50	54+
1971	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
1972	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
1973	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
1974	8	24	41	47	43	24	21	12	10	1	3	1	0	0	0	0	0	0
1975	4	29	28	36	35	33	24	10	9	1	1	1	0	0	0	0	0	0
1976	5	37	44	64	100	70	46	30	22	19	6	6	2	2	2	0	0	0
1977	1	11	40	48	32	32	25	9	11	3	0	0	2	1	0	0	0	0
1978	5	10	26	48	42	41	10	20	22	9	1	2	0	2	0	0	0	0
1979	10	48	115	89	96	124	105	59	72	39	47	15	10	3	12	4	0	0
1980	1	20	23	33	38	27	21	23	22	15	7	7	6	2	1	0	0	0
1981	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
1982	0	0	0	0	0	0	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	0	0	0	0	0	0
1984	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
1985	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
1986	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0

Table 1. Cont.

Area VE – Japan

Year/Age	2	5	8	11	14	17	20	23	26	29	32	35	38	41	44	47	50	54+
1971	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
1972	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
1973	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
1974	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
1975	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
1976	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
1977	1	3	15	10	6	4	6	4	2	0	1	1	0	0	0	0	0	0
1978	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
1979	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
1980	5	18	31	22	13	24	14	13	15	16	6	6	3	0	3	2	0	0
1981	0	4	4	3	4	6	1	2	3	1	1	1	0	0	0	0	0	0
1982	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
1983	1	10	12	10	7	6	6	5	2	0	1	3	0	0	0	0	0	0
1984	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
1985	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
1986	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
1987	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
1988	13	34	27	28	39	25	21	15	8	10	5	5	5	0	0	0	0	0
1989	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
1990	1	9	11	9	16	19	21	10	10	4	3	4	2	1	2	1	0	0
1991	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
1992	12	5	10	16	3	6	6	11	9	8	6	1	3	1	0	0	0	0
1993	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
1994	22	14	21	21	21	21	10	12	15	11	5	9	4	2	0	0	0	0
1995	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
1996	11	9	9	21	15	15	15	13	13	8	13	3	3	7	2	0	1	1
1997	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
1998	24	5	11	8	20	12	9	12	14	8	10	5	4	0	1	1	1	1
1999	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
2000	8	9	19	18	15	17	4	10	14	15	8	5	6	2	3	1	3	5
2001	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
2002	19	26	19	27	22	26	16	15	12	12	14	8	5	3	5	1	2	2
2003	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0

Area VE – USSR

Year/Age	2	5	8	11	14	17	20	23	26	29	32	35	38	41	44	47	50	54+
1971	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
1972	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
1973	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
1974	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
1975	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
1976	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
1977	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
1978	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
1979	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
1980	0	37	62	49	23	50	29	28	32	30	12	9	6	0	5	3	0	0
1981	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
1982	0	0	0	0	0	0	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	0	0	0	0	0	0
1984	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
1985	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
1986	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0

Table 1. Cont.

Area VIW - Japan

Year/Age	2	5	8	11	14	17	20	23	26	29	32	35	38	41	44	47	50	54+
1971	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
1972	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
1973	0	0	0	3	5	0	5	0	0	0	0	0	0	0	0	0	0	0
1974	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
1975	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
1976	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
1977	3	35	41	27	32	20	32	23	15	4	2	0	0	3	0	0	0	0
1978	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
1979	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
1980	5	37	36	34	18	14	17	7	12	5	6	2	3	1	1	0	0	0
1981	42	33	50	44	27	26	23	15	12	4	5	1	1	1	0	0	0	0
1982	14	32	42	55	45	48	20	21	20	8	1	3	0	0	0	0	0	0
1983	26	57	77	98	63	51	45	22	18	5	7	1	3	0	0	0	2	0
1984	21	49	52	57	61	48	36	22	15	6	2	1	0	0	0	0	0	0
1985	66	57	40	50	63	41	24	20	18	9	3	3	0	0	1	0	0	0
1986	13	35	34	47	65	66	49	47	27	18	8	3	2	0	0	0	0	0
1987	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
1988	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
1989	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
1990	0	0	2	2	0	4	3	2	0	0	1	0	0	0	0	0	0	0
1991	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
1992	0	1	0	2	5	2	1	2	1	6	0	1	1	0	0	1	0	0
1993	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
1994	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
1995	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
1996	8	6	15	16	18	17	11	11	16	11	7	5	5	6	1	3	1	0
1997	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
1998	31	4	5	1	3	3	1	2	3	2	1	0	2	0	0	1	0	0
1999	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
2000	37	2	9	12	12	17	6	7	15	6	5	5	4	4	0	0	0	0
2001	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
2002	26	25	6	6	9	8	8	3	6	2	3	5	0	3	0	1	0	0
2003	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0

Area VIW – USSR

Year/Age	2	5	8	11	14	17	20	23	26	29	32	35	38	41	44	47	50	54+
1971	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
1972	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
1973	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
1974	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
1975	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
1976	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
1977	2	28	20	21	27	18	32	17	13	5	0	0	0	2	0	0	0	0
1978	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
1979	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
1980	1	5	11	10	4	5	6	3	5	2	3	1	1	1	1	0	0	0
1981	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
1982	11	36	72	100	66	76	30	35	25	13	1	4	0	0	0	0	0	0
1983	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
1984	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
1985	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
1986	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0

Table 2 Abundance estimates from sightings surveys (see text for source details).

Area IIIE

Survey	Year to which applies	Estimate (CV)
IDCR 1979/80	1979	80551 (0.381)
IDCR 1987/88	1987	37428 (0.426)
IDCR 1992/93 + 1994/95	1994	20465 (0.238)
JARPA 1995/96	1995	12766 (0.323)
JARPA 1997/98	1997	7710 (0.445)
JARPA 1999/00	1999	15580 (0.687)
JARPA 2001/02	2001	58169 (0.413)
JARPA 2003/04	2003	34949 (0.295)

Area IV

Survey	Year to which applies	Estimate (CV)
IDCR 1978/79	1978	130333 (0.178)
IDCR 1988/89	1988	84815 (0.288)
IDCR 1994/95+1998/99	1998	13409 (0.279)
JARPA 1989/90	1989	54772 (0.231)
JARPA 1991/92	1991	56774 (0.258)
JARPA 1993/94	1993	41895 (0.211)
JARPA 1995/96	1995	42882 (0.245)
JARPA 1997/98	1997	29683 (0.266)
JARPA 1999/00	1999	49922 (0.168)
JARPA 2001/02	2001	67954 (0.169)
JARPA 2003/04	2003	47818 (0.358)

Area VW

Survey	Year to which applies	Estimate (CV)
IDCR 1980/81	1980	78093 (0.470)
IDCR 1985/86	1985	77194 (0.249)
IDCR 1991/92	1991	10055 (0.282)
IDCR 2001/02+2002/03	2001	46169 (0.174)
JARPA 1990/91	1990	65129 (0.279)
JARPA 1992/93	1992	44047 (0.291)
JARPA 1994/95	1994	21601 (0.322)
JARPA 1996/97	1996	26333 (0.373)
JARPA 1998/99	1998	87626 (0.311)
JARPA 2000/01	2000	20548 (0.290)
JARPA 2002/03	2002	108783 (0.230)

Table 2 cont.

Area VE

Survey	Year to which applies	Estimate (CV)
IDCR 1980/81	1980	164993 (0.328)
IDCR 1985/86	1985	172828 (0.147)
IDCR 1991/92	1991	187266 (0.210)
IDCR 2002/03+2003/04	2003	100658 (0.170)
JARPA 1990/91	1990	124758 (0.287)
JARPA 1992/93	1992	81466 (0.284)
JARPA 1994/95	1994	141017 (0.297)
JARPA 1996/97	1996	142304 (0.293)
JARPA 1998/99	1998	38230 (0.378)
JARPA 2000/01	2000	152580 (0.236)
JARPA 2002/03	2002	83166 (0.197)

Area VIW

Survey	Year to which applies	Estimate (CV)
IDCR 1983/84	1983	67161 (0.227)
IDCR 1990/91	1990	8394 (0.294)
IDCR 1995/96	1995	33323 (0.230)
JARPA 1996/97	1996	13556 (0.284)
JARPA 1998/99	1998	40430 (0.273)
JARPA 2000/01	2000	23426 (0.236)
JARPA 2002/03	2002	13436 (0.225)

Table 3 Annual genetically based estimates of the proportions of minke whales in Area VW that belong to the I-stock. The following baseline data were used: I-stock Baseline: Area IV, all JARPA surveys (n=2655), P-stock Baseline: Area VE+VIW, all JARPA surveys (n=1637) (source: Appendix 3 of Government of Japan 2005).

Year	Year to which applies	I-stock proportion	SD
1990/91	1990	0.625	0.125
1992/93	1992	0.491	0.151
1994/95	1994	0.605	0.171
1996/97	1996	0.245	0.158
1998/99	1998	0.651	0.136
2000/01	2000	0.485	0.171
2002/03	2002	0.427	0.219

Table 4. Results for the Reference cases and the various stock hypotheses together with sensitivity tests. Increase rates are given as annual proportions. The contributions to the total negative log-likelihood (-ln$L$(total)), in terms of the notation in the text, are –ln$L$(CAA)=-lnL_3, -ln$L$(indices)=-lnL_1-lnL_2(-ln L_5 for the mixing model), -ln$L$(p_y)=-lnL_4. Chi2= χ^2 is defined in equation 20 of Butterworth *et al*. (1999). The value of $\bar{p}$ is the estimated average proportion of the whales to be found in the relevant Area. SDSR is the standard deviation of the standardized residuals; for the abundance indices the standardization is in terms of the survey sampling CVs for each survey, whereas for the proportion p_y in Area IV it is in terms of the standard deviation assumed to apply to this distribution. Estimated CVs, where given, are based upon the Hessian approximation – this was cross-checked against likelihood profile estimation for the CV of M, and found to reflect good accuracy.

Scenario	Ny,1 incr.rate 45-68	$N_{83,1}/N_{68,1}$	$N_{lstyr-5,1}/N_{68,1}$	M (CV)	Ny incr.rate 80-lstyr	-lnL (total)	-lnL (CAA)	lnL (indices	-lnL (Py)	Chi^2/DF	$\bar{p}$ 1 (CV)	$\bar{p}$ 2	$\bar{p}$ 3	$\bar{p}$ 4		SDSR (abur	SDSR (*p1*)	SDSR (*p2*)	SDSR (*p3*)	SDSR (*p4*)	Others
Initial 1 stock comp. IV & V																					
Mori (2005) (includes Russian CAA)	0.043	0.550	0.208	0.071 (0.119)	-0.027	298.682	326.762	9.958	-38.038	0.960	0.185 (0.201)					0.974	0.916				
m =30 (excludes Russian CAA)	0.042	0.528	0.199	0.072 (0.119)	-0.027	284.429	312.523	9.987	-38.08	1.036	0.185 (0.201)					0.975	0.914				
																					q
1 stock comp. IIIE & IV & VW	Ny,1 incr.rate 45-68										$\bar{p}$ [Area IV]	$\bar{p}$ [Area IIIE]									
m =30	0.047	0.501	0.237	0.063 (0.167)	-0.017	297.110	332.625	15.265	-50.780	1.065	0.424 (0.227)	0.210 (0.378)				1.009	1.047	0.727			
-q estimated	0.047	0.500	0.236	0.063 (0.210)	-0.017	297.110	332.626	15.286	-50.801	1.065	0.424 (0.227)	0.210 (0.377)				1.010	1.045	0.728			1.073
m =45	0.061	0.447	0.195	0.067 (0.149)	-0.021	457.043	492.475	15.306	-50.738	0.995	0.421 (0.227)	0.213 (0.373)				1.010	1.039	0.731			
fit only JARPA (*m* =30)	0.077	0.676	0.522	0.030 (0.002)	0.014	298.886	331.859	8.392	-41.365	1.041	0.432 (0.129)	0.129 (0.510)				0.916	0.743	0.643			
fit only IDCR (*m* =30)	0.014	0.328	0.088	0.098 (0.164)	-0.052	312.446	332.291	4.179	-24.024	1.023	0.386 (0.235)	0.276 (0.301)	M(0-3)	M(10-30)	M(>35)	0.914	0.958	0.588			
M linear by age (*m* =30)	0.049	0.502	0.228	0.073	-0.017	299.316	334.344	15.496	-50.524	1.067	0.425 (0.227)	0.209 (0.379)	0.125 (0.285)	0.060 (0.193)	0.030 (0.181)	1.016	1.057	0.734			
M linear by age (*m* =45)	0.061	0.46	0.196	0.075	-0.021	460.899	495.569	15.651	-50.321	1.005	0.422 (0.227)	0.213 (0.374)	0.135 (0.254)	0.060 (0.173)	0.099 (0.156)	1.022	1.053	0.742			
down weight JARPA CAA by 0.1	-0.014	0.262	0.173	0.127 (0.162)	-0.029	73.364	132.008	15.076	-73.72	0.902	0.415 (0.166)	0.215 (0.268)				1.003	0.735	0.426			
down weight commercial CAA by 0.1	0.037	0.555	0.242	0.067 (0.160)	-0.023	189.699	225.402	15.199	-50.901	1.047	0.421 (0.228)	0.214 (0.372)				1.006	1.031	0.727			
no IDCR 78/79	0.063	0.579	0.349	0.045 (0.335)	-0.001	298.217	332.129	16.485	-50.396	1.060	0.392 (0.233)	0.220 (0.353)				1.066	0.962	0.742			
no IDCR 78/79, 1979/80	0.076	0.643	0.472	0.029 (0.540)	0.012	299.276	331.728	15.744	-48.196	1.056	0.410 (0.300)	0.183 (0.404)				1.061	1.025	0.682			
no IDCR + down weight commercial CAA by 0.1	0.073	0.749	0.566	0.030 (0.006)	0.012	192.385	225.348	8.317	-41.279	1.024	0.426 (0.227)	0.135 (0.495)				0.912	0.739	0.629			
no JARPA + down weight JARPA CAA by 0.1	0.013	0.317	0.09	0.100 (0.188)	-0.051	119.134	139.284	4.103	-24.253	1.032	0.383 (0.235)	0.279 (0.298)				0.906	0.944	0.582			
1 stock comp. VE & VIW	Ny,1 incr.rate 54-68										$\bar{p}$ [Area VE]										
m =30	0.037	0.489	0.392	0.090 (0.132)	-0.039	114.621	153.889	9.233	-48.501	1.096	0.667 (0.169)					1.013	1.007				
-q estimated	0.048	0.566	0.517	0.080 (0.225)	-0.030	108.401	153.853	8.857	-54.309	1.095	0.657 (0.162)					0.992	1.038				0.756
m =45	0.032	0.511	0.466	0.087 (0.124)	-0.033	170.360	179.300	8.855	-17.796	1.032	0.839 (0.093)					0.992	0.833				
fit only JARPA (*m* =30)	0.054	0.619	0.622	0.074 (0.369)	-0.024	151.005	153.759	6.149	-8.903	1.069	0.821 (0.117)					1.057	0.744				
fit only IDCR (*m* =30)	0.045	0.551	0.485	0.082 (0.151)	-0.032	145.479	153.906	3.405	-11.832	1.071	0.858 (0.052)		M(0-3)	M(10-30)	M(>35)	0.986	0.982				
M linear by age (*m* =30)	0.038	0.492	0.376	0.102	-0.040	111.839	155.665	10.073	-53.899	1.108	0.664 (0.161)		0.153 (0.400)	0.089 (0.137)	0.030 (0.468)	1.058	1.046				
M linear by age (*m* =45)	0.034	0.526	0.471	0.096	-0.033	172.459	181.401	8.894	-17.837	1.042	0.840 (0.092)		0.142 (0.428)	0.085 (0.134)	0.085 (0.310)	0.994	0.834				
down weight JARPA CAA by 0.1	0.053	0.560	0.432	0.080 (0.209)	-0.032	46.956	55.508	7.559	-16.111	1.082	0.839 (0.111)					0.917	0.821				
down weight commercial CAA by 0.1	0.032	0.586	0.519	0.082 (0.148)	-0.032	104.424	112.499	8.008	-16.083	1.120	0.836 (0.112)					0.943	0.806				
no IDCR + down weight commercial CAA by 0.1	0.038	0.642	0.631	0.076 (0.356)	-0.026	109.714	112.471	6.123	-8.879	1.095	0.820 (0.117)					1.055	0.738				
no JARPA + down weight JARPA CAA by 0.1	0.054	0.577	0.429	0.078 (0.210)	-0.032	46.968	55.688	3.138	-11.858	1.069	0.861 (0.051)					0.947	0.994				
1stock comp. IV & VW	Ny,1 incr.rate 45-68										$\bar{p}$ [Area IV]										
m =30	0.055	0.553	0.258	0.055 (0.197)	-0.012	316.496	323.063	11.208	-17.776	0.987	0.523 (0.239)					1.076	1.079				
-q estimated	0.058	0.588	0.287	0.052 (0.225)	-0.009	315.497	323.16	11.219	-18.882	0.987	0.528 (0.226)					1.010	1.446				0.85
m =45	0.079	0.535	0.258	0.049 (0.214)	-0.008	497.852	493.522	12.154	-7.824	0.972	0.559 (0.218)					1.051	1.463				
fit only JARPA (*m* =30)	0.078	0.702	0.467	0.030 (0.004)	0.01	313.929	321.108	5.263	-12.442	0.976	0.512 (0.230)					0.838	0.895				
fit only IDCR (*m* =30)	0.024	0.371	0.101	0.088 (0.197)	-0.045	325.659	323.717	2.811	-0.869	0.970	0.583 (0.212)		M(0-3)	M(10-30)	M(>35)	0.896	1.691				
M linear by age (*m* =30)	0.057	0.554	0.250	0.065	-0.013	327.725	323.775	11.982	-8.031	0.984	0.558 (0.219)		0.114 (0.327)	0.052 (0.218)	0.030 (0.246)	1.044	1.455				
1stock comp. IIIE & IV & VW & VE & VIW	Ny,1 incr.rate 45-68										$\bar{p}$ [Area IV]	$\bar{p}$ [Area IIIE]	$\bar{p}$ [Area VW]	$\bar{p}$ [Area VE]							
m =30	0.04	0.507	0.239	0.074 (0.104)	-0.027	178.220	340.618	35.537	-197.935	1.128	0.182 (0.227)	0.018 (0.794)	0.155 (0.250)	0.570 (0.093)		1.442	0.731	1.286	1.099	0.730	
-q estimated	0.036	0.481	0.216	0.078 (0.111)	-0.030	177.858	340.702	35.610	-198.453	1.128	0.178 (0.230)	0.018 (0.794)	0.153 (0.252)	0.576 (0.092)		1.496	0.720	1.285	1.086	0.738	1.105
m=45	0.06	0.467	0.220	0.076 (0.098)	-0.027	331.395	493.774	35.562	-197.941	1.017	0.181 (0.228)	0.018 (0.794)	0.155 (0.250)	0.570 (0.730)		1.441	0.731	1.286	1.099	0.730	
fit only JARPA (*m* =30)	0.081	0.848	0.750	0.030 (0.005)	0.016	212.966	339.846	32.653	-159.534	1.004	0.209 (0.156)	0.010 (0.799)	0.190 (0.165)	0.526 (0.076)		1.451	0.432	1.383	0.757	0.650	
fit only IDCR (*m* =30)	0.017	0.364	0.114	0.099 (0.092)	-0.051	215.582	340.456	32.14	-157.013	1.069	0.164 (0.155)	0.007 (0.801)	0.122 (0.184)	0.632 (0.052)		1.945	0.596	1.487	0.914	0.659	
2stock (I-stock and P-stock), mixing at VW	Ny,1 incr.rate 45-68										$\bar{p}$ [Area IV]	$\bar{p}$ [Area IIIE]									
m =30, est 2 M's (1st iteration)											$\bar{p}$ [Area VE]	$\bar{p}$ [Area VW-E]									
I-stock	0.035	0.465	0.187	0.074 (0.154)	-0.026	424.829	495.683	31.163	-102.018	1.056	0.521 (0.171)	0.277 (0.289)				1.076	0.992	0.596			
P-stock	0.093	0.529	0.517	0.070 (0.131)	-0.026						0.751 (0.080)	0.118 (0.380)				0.929	0.982	2.107			
m =30, est 2 M's (2nd iteration)																					
I-stock	0.035	0.459	0.189	0.075 (0.153)	-0.026	423.222	494.156	31.132	-102.066	1.055	0.521 (0.172)	0.277 (0.289)				1.075	0.992	0.595			
P-stock	0.093	0.541	0.525	0.069 (0.132)	-0.026						0.751 (0.081)	0.118 (0.381)				0.929	0.981	2.105			
m =45, est 2 M's																					
I-stock	0.048	0.421	0.154	0.079 (0.131)	-0.032	668.431	739.315	31.159	-102.043	1.005	0.517 (0.172)	0.283 (0.284)				1.081	0.978	0.596			
P-stock	0.075	0.498	0.518	0.074 (0.120)	-0.025						0.751 (0.080)	0.118 (0.380)				0.926	0.991	2.146			
fit only JARPA																					
I-stock	0.075	0.681	0.529	0.030 (0.003)	0.015	442.63	490.831	17.625	-65.826	0.978	0.552 (0.166)	0.186 (0.384)				0.892	0.684	0.563			
P-stock	0.125	0.828	1.246	0.037 (0.421)	0.005						0.727 (0.084)	0.145 (0.332)				0.978	0.996	1.169			
M linear by age (*m* =30)													M(0-3)	M(10-30)	M(>35)						
I-stock	0.037	0.465	0.177	0.086	-0.027	430.249	500.391	31.612	-101.754	1.062	0.522 (0.171)	0.277 (0.289)	0.148 (0.224)	0.071 (0.169)	0.030 (0.143)	1.090	1.002	0.605			
P-stock	0.100	0.585	0.601	0.073	-0.023						0.752 (0.080)	0.118 (0.381)	0.113 (0.452)	0.063 (0.200)	0.667 (5.846)	0.928	0.982	2.109			
M linear by age (*m* =45)																					
I-stock	0.048	0.432	0.153	0.089	-0.031	674.309	744.228	31.839	-101.758	1.016	0.518 (0.172)	0.283 (0.284)	0.153 (0.211)	0.073 (0.146)	0.101 (0.153)	1.1018	0.9871	0.6058			
P-stock	0.070	0.515	0.533	0.077	-0.024						0.751 (0.080)	0.118 (0.380)	0.107 (0.473)	0.069 (0.135)	0.112 (0.177)	0.926	0.995	2.1509			
fit only IDCR (not converge)																					

Table 5. Estimated parameters from the stock-recruitment model of equations (28-37) of the text for stock hypothesis (i) onestock comprising Areas IIIE+IV+VW (I-stock) and (ii) one stock comprising Areas VE+VIW (P-stock) for Reference cases and various sensitivities.

Scenario	A	γ	K_1^f	K_2^f	K_3^f	$MSYR_{1+}$	K_2^f/K_1^f	K_3^f/K_2^f
1 stock comp. IIIE+IV+VW								
fit to both JARPA & IDCR/SOWER (m=30) ("Reference case")	1.90	2.57	21305	78921	36151	0.05	3.7	0.5
fit only JARPA (m=30)	5.00	3.62	9322	57315	60754	0.07	6.1	1.1
fit only IDCR/SOWER (m=30)	1.12	2.39	74218	115880	24643	0.04	1.6	0.2
fit to both JARPA & IDCR/SOWER (m=30) but exclude 1978/79 of IDCR/SOWER	3.02	2.94	10423	53965	37841	0.06	5.2	0.7
no IDCR + down weight commercial CAA by 0.1	4.96	3.28	3667	21399	22280	0.07	5.8	1.0
no JARPA + down weight scientific CAA by 0.1	1.18	2.42	76500	115385	24537	0.05	1.5	0.2
1 stock comp. VE+VIW								
fit to both JARPA & IDCR/SOWER (m=30) ("Reference case")	0.95	1.83	28434	110093	35039	0.04	3.9	0.3
fit only JARPA (m=30)	1.46	2.31	12044	76627	37710	0.05	6.4	0.5
fit only IDCR/SOWER (m=30)	1.17	2.06	20195	100974	39099	0.04	5.0	0.4
no IDCR + down weight commercial CAA by 0.1	1.08	2.03	21406	83547	37829	0.04	3.9	0.5
no JARPA + down weight scientific CAA by 0.1	1.40	2.26	16049	108889	42821	0.05	6.8	0.4

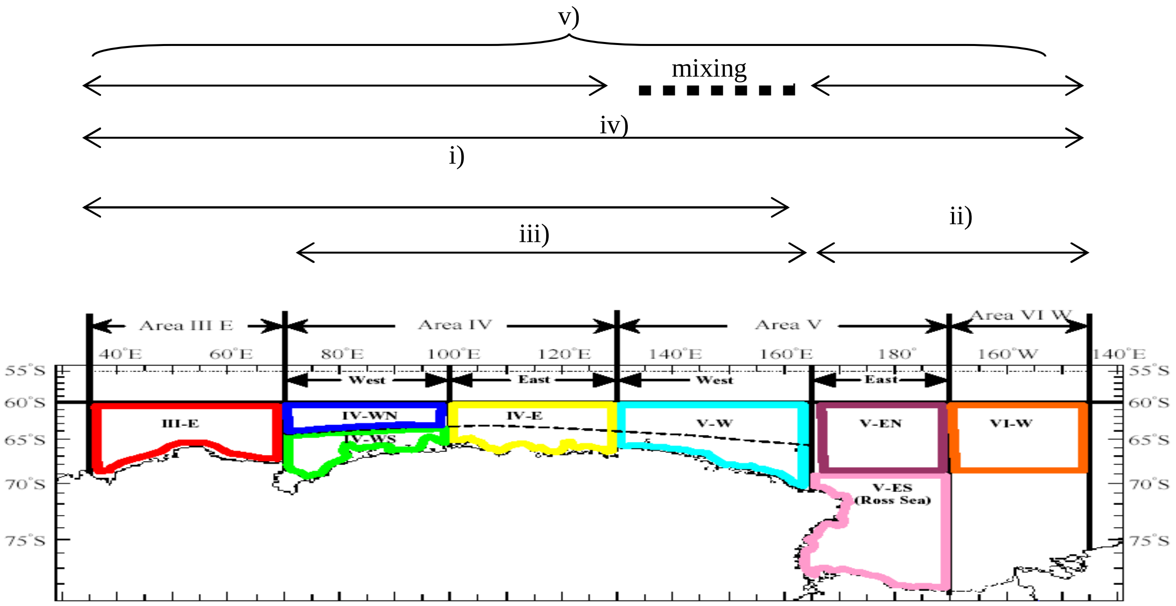


Figure 1. Graphical illustration of the various stock hypotheses (i-v) tested for Antarctic minke whales (the plot showing the strata are redrawn from Pastene *et al*. (2005).

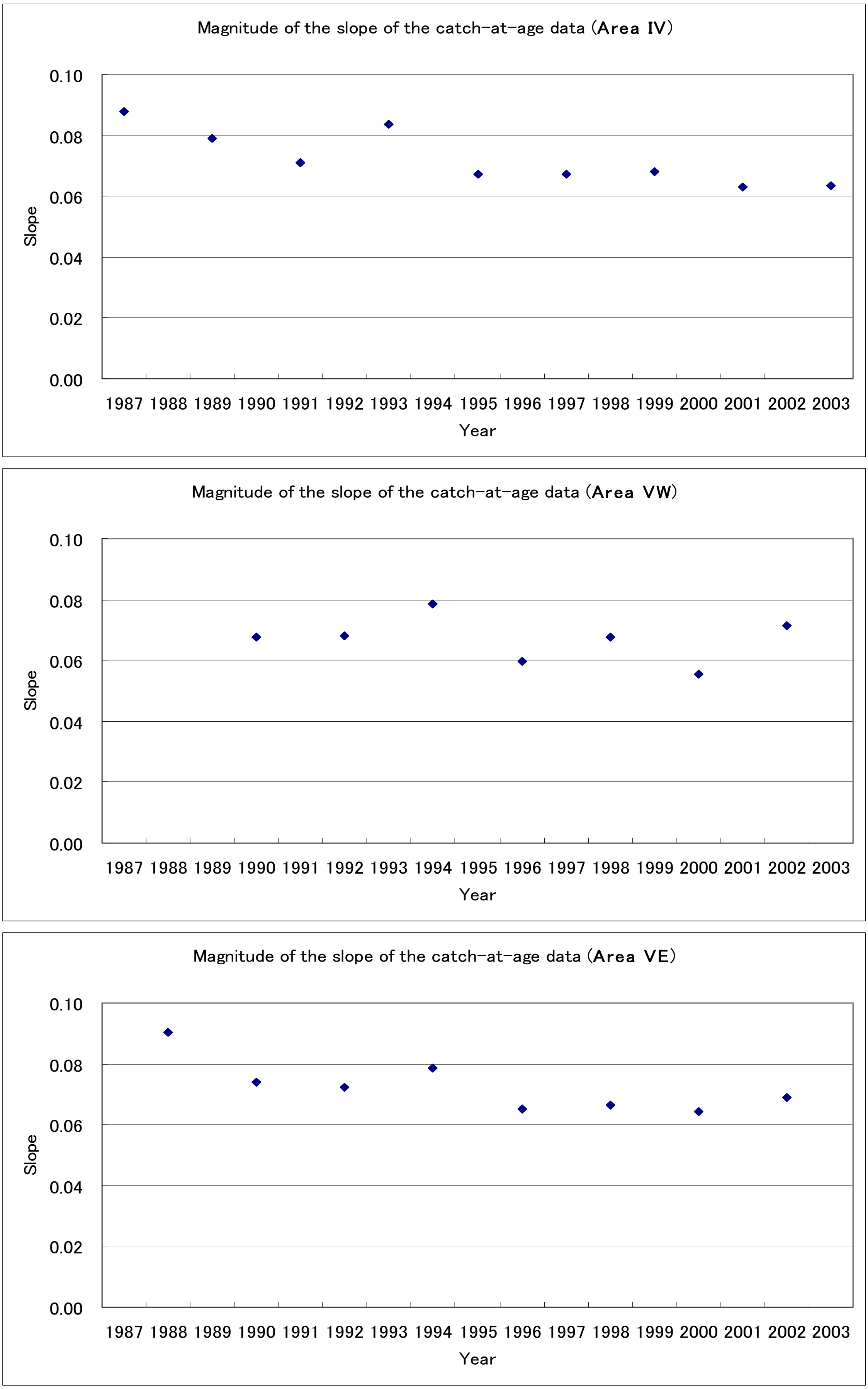


Figure 2. Chapman-Robson (1960) estimates of catch curve slopes (see text) for each year of the scientific research whaling.

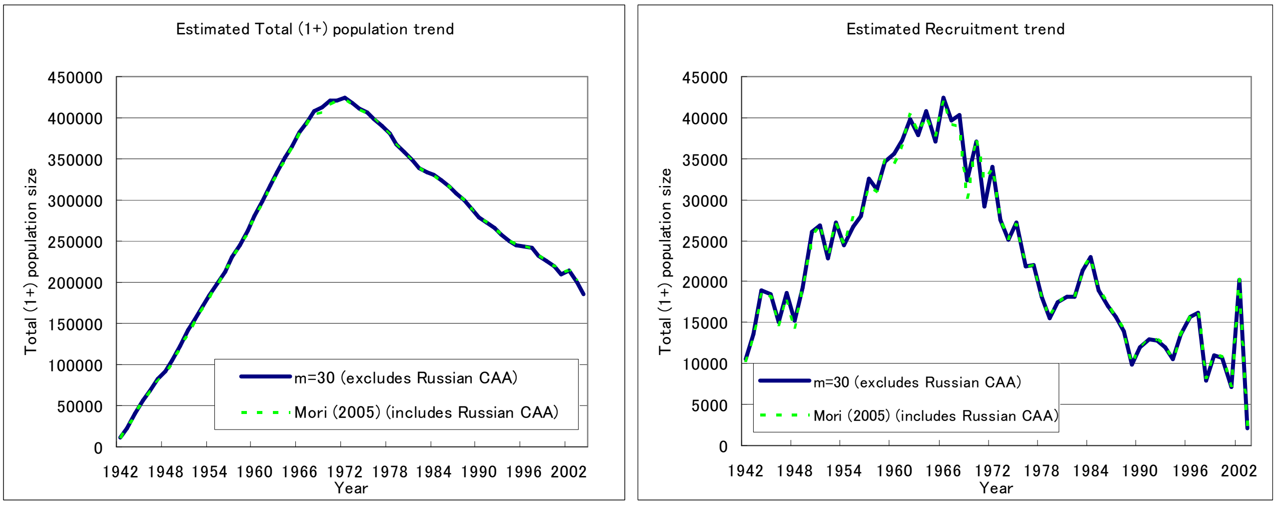


Figure 3. Estimated total population size and recruitment ($N_{y,1}$) trajectories for the initial scenario (Area IV and V combined) which the model is fit only to the Japanese catch-at-age proportion. These are compared to earlier comparable results (Mori 2005) where the Japanese and Russian commercial fleets are assumed to have the same selectivity-at age. The results are shown for *m*=30.

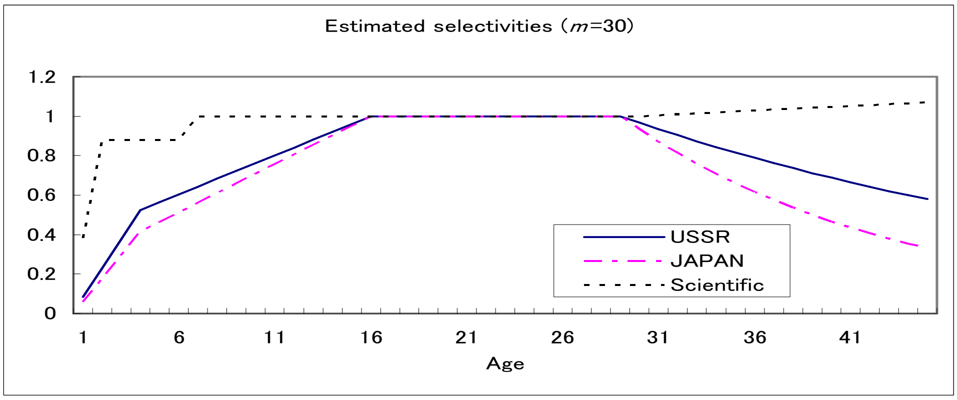


Figure 4. Estimated selectivity by age for the commercial and scientific catches for the initial scenario (*m*=30). The selectivities have been normalized so that S^{c}_{16-30} =1 and S^{s}_{7-30} =1 . The commercial selectivity trend outside the age range of 16-30 are estimated as detailed in equations (23)-(26). The scientific selectivity is as estimated for the initial scenario to age 30. Thereafter it is estimated using equations (23), (24) and (26).

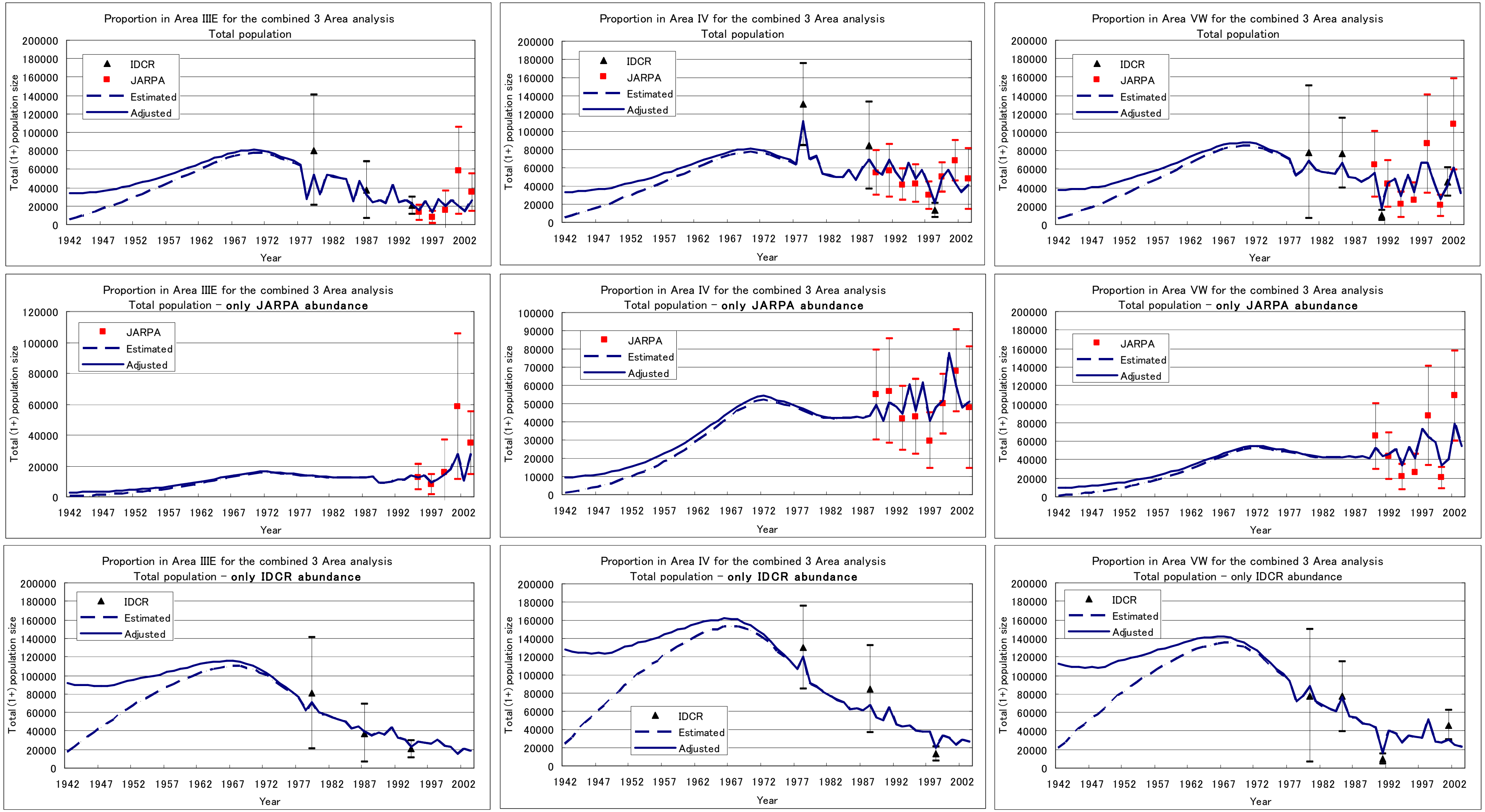


Figure 5a. Fits of the ADAPT-VPA model to the total (1+) abundance estimates for Areas IIIE, IV and VW separately for each Area for the Area IIIE+IV+VW scenario (so-called "I-stock") for three cases 1: both IDCR/SOWER and JARPA abundance estimates are fitted, 2:only JARPA abundance estimates are fitted and 3: only IDCR abundance estimates are fitted. The abundance plots include the survey estimates of abundance together with their survey sampling estimated 95% confidence intervals. The difference between the "estimated" and "adjusted" total population sizes is explained in Mori and Butterworth (2005).

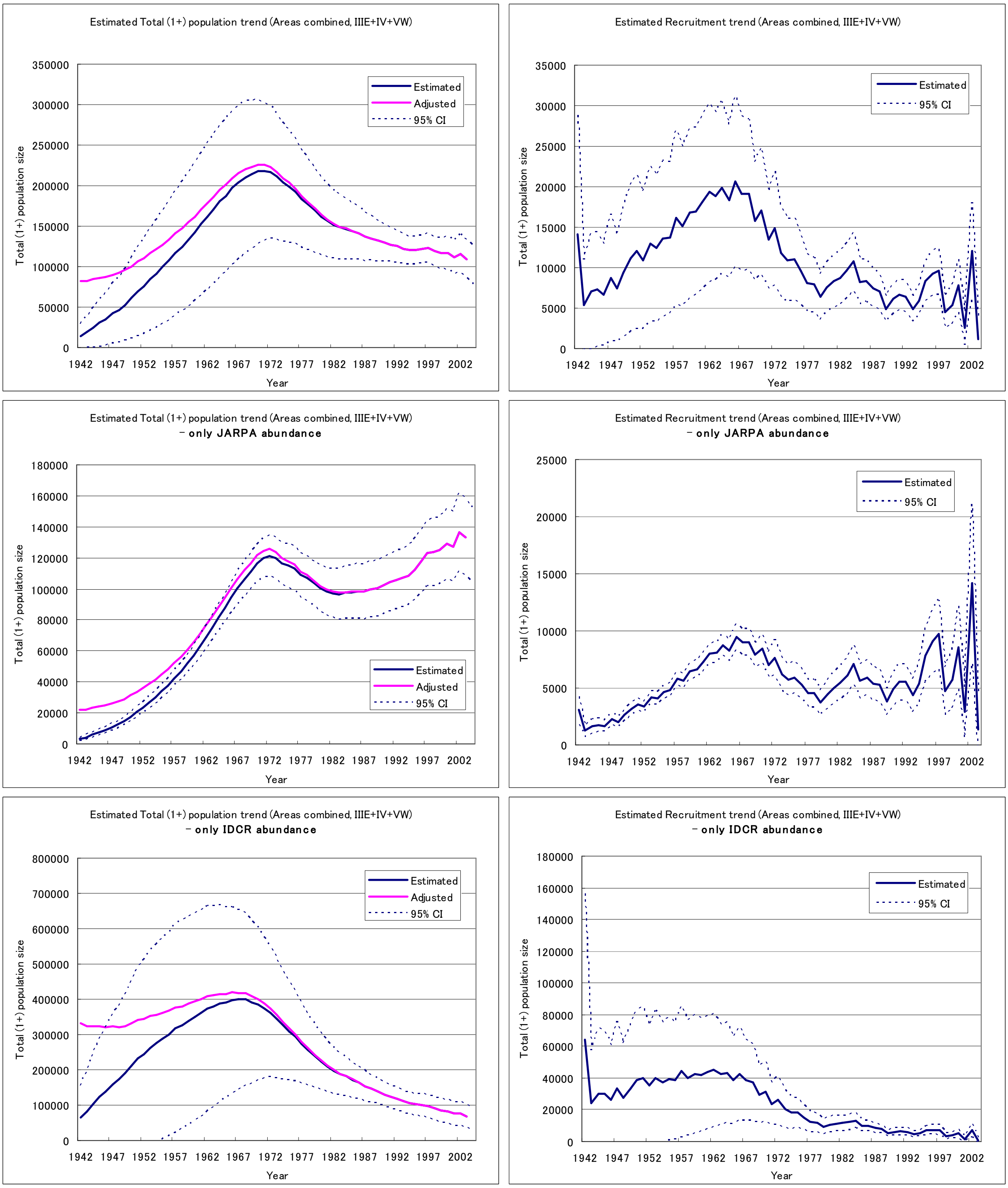


Figure 5b. Estimated total (1+) population and recruitment trend for the Area IIIE+IV+VW case (so-called "I-stock") for three cases 1: both IDCR/SOWER and JARPA abundance estimates are fitted, 2: only JARPA abundance estimates are fitted and 3: only IDCR abundance estimates are fitted. The difference between the "estimated" and "adjusted" total population sizes is explained in Mori and Butterworth (2005).

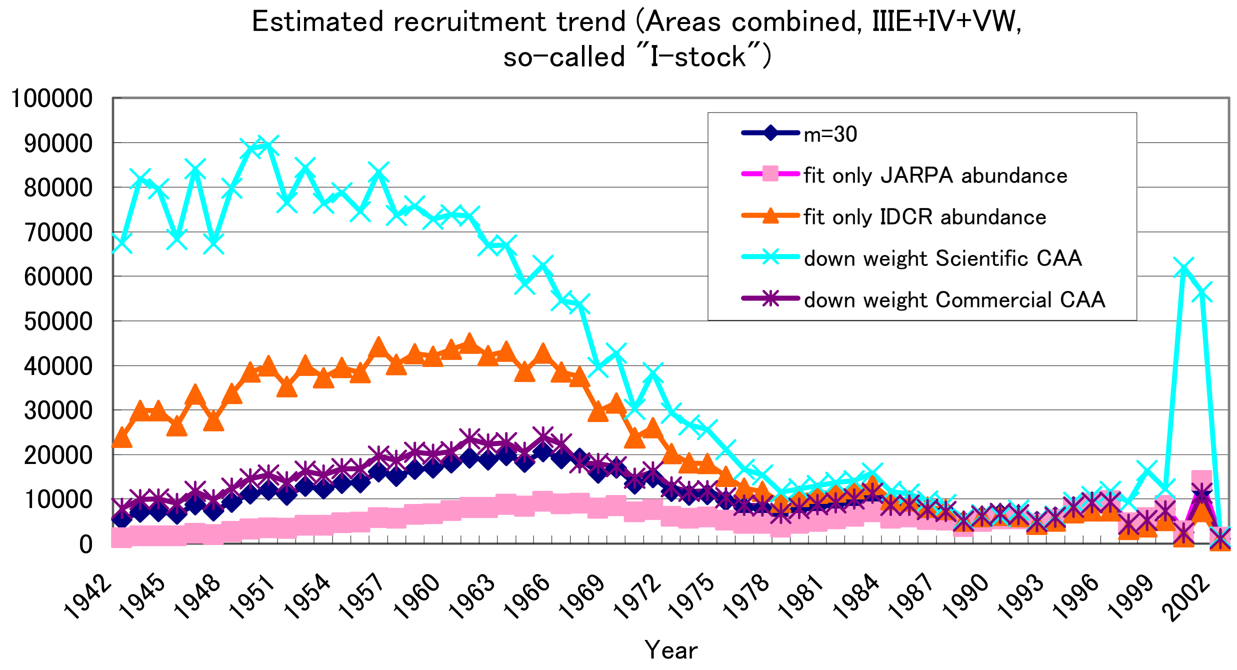


Figure 6. Estimated recruitment trend for the Areas IIIE+IV+VW combined assessment case (so-called "I-stock") for various sensitivities. Details of these sensitivity tests are given in the text.

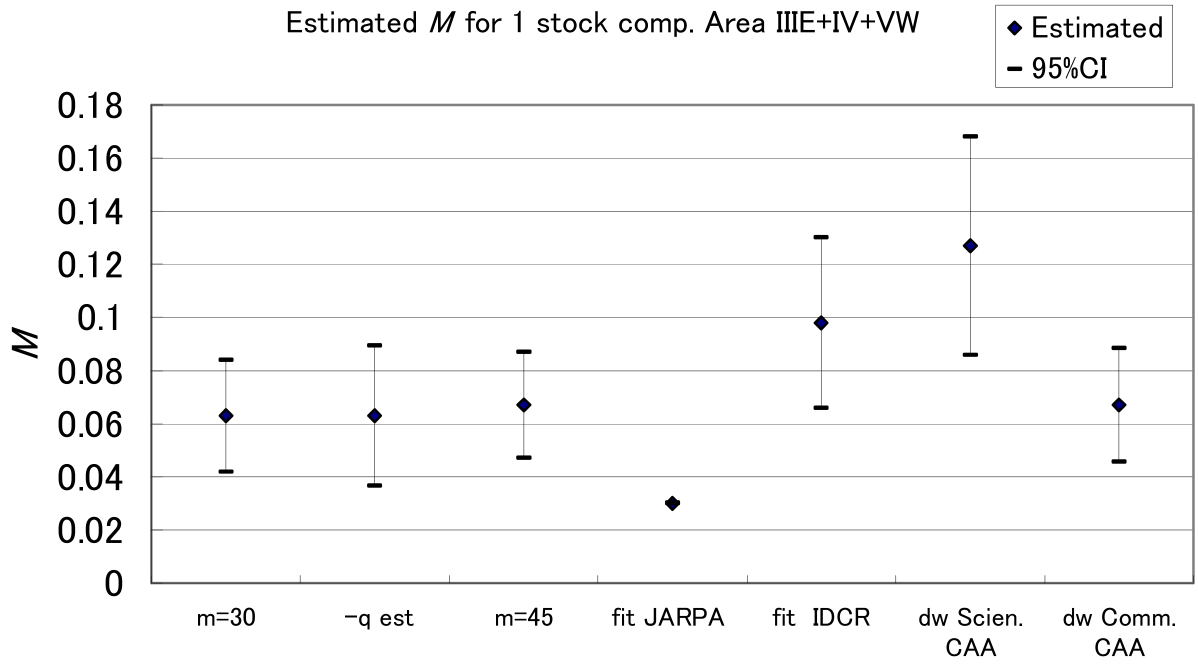


Figure 7. Estimated *M* for the Areas IIIE+IV+VW combined assessment case (so-called "I-stock") for various sensitivities. Details of these sensitivity tests are given in the text.

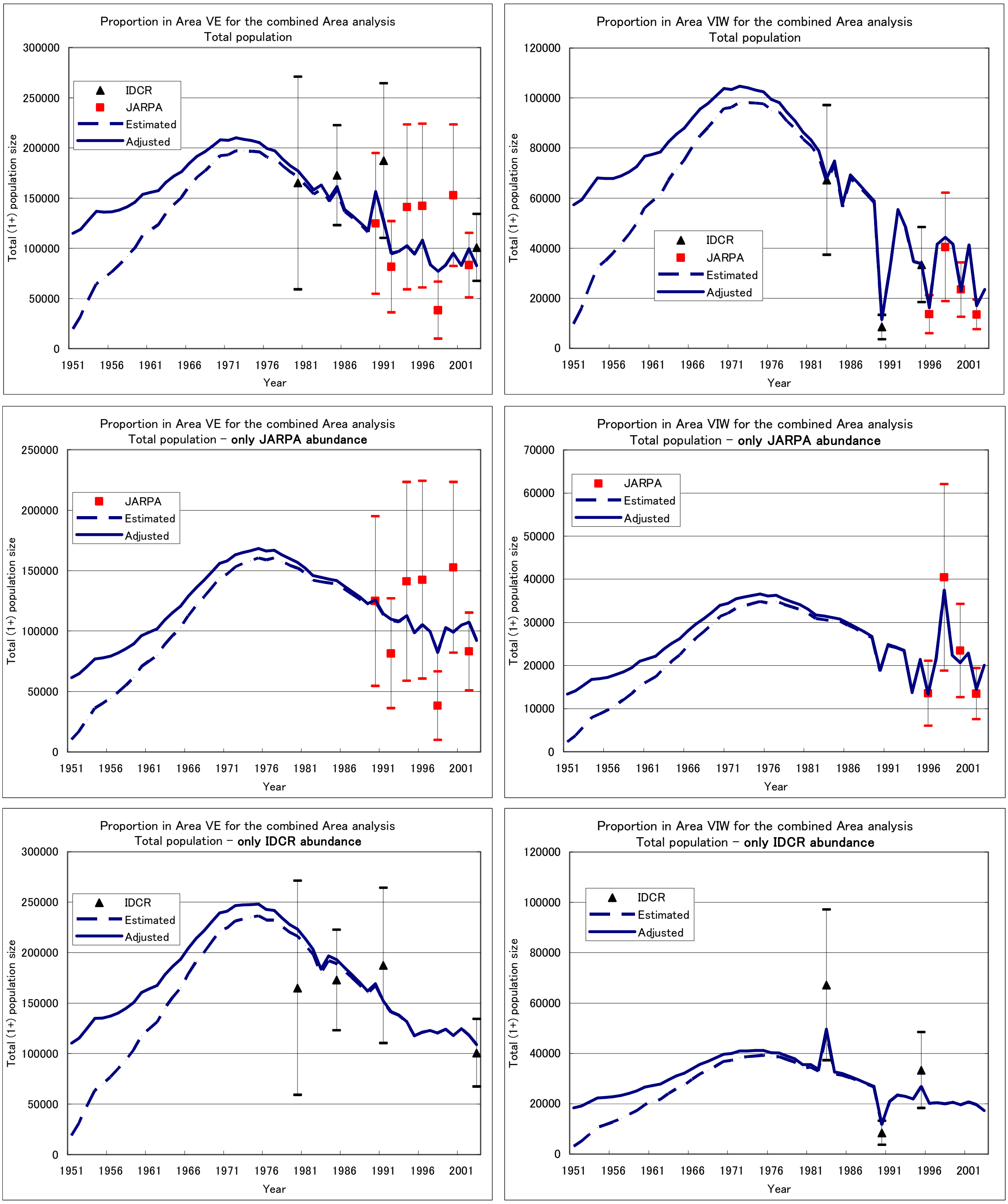


Figure 8a. Fits of the ADAPT-VPA model to the total (1+) abundance estimates for Areas VE and VIW separately for each Area for the AreaVE+VIW scenario (so-called "P-stock") for three cases 1: both IDCR/SOWER and JARPA abundance estimates are fitted, 2:only JARPA abundance estimates are fitted and 3: only IDCR abundance estimates are fitted. The abundance plots include the survey estimates of abundance together with their survey sampling estimated 95% confidence intervals. The difference between the "estimated" and "adjusted" total population sizes is explained in Mori and Butterworth (2005).

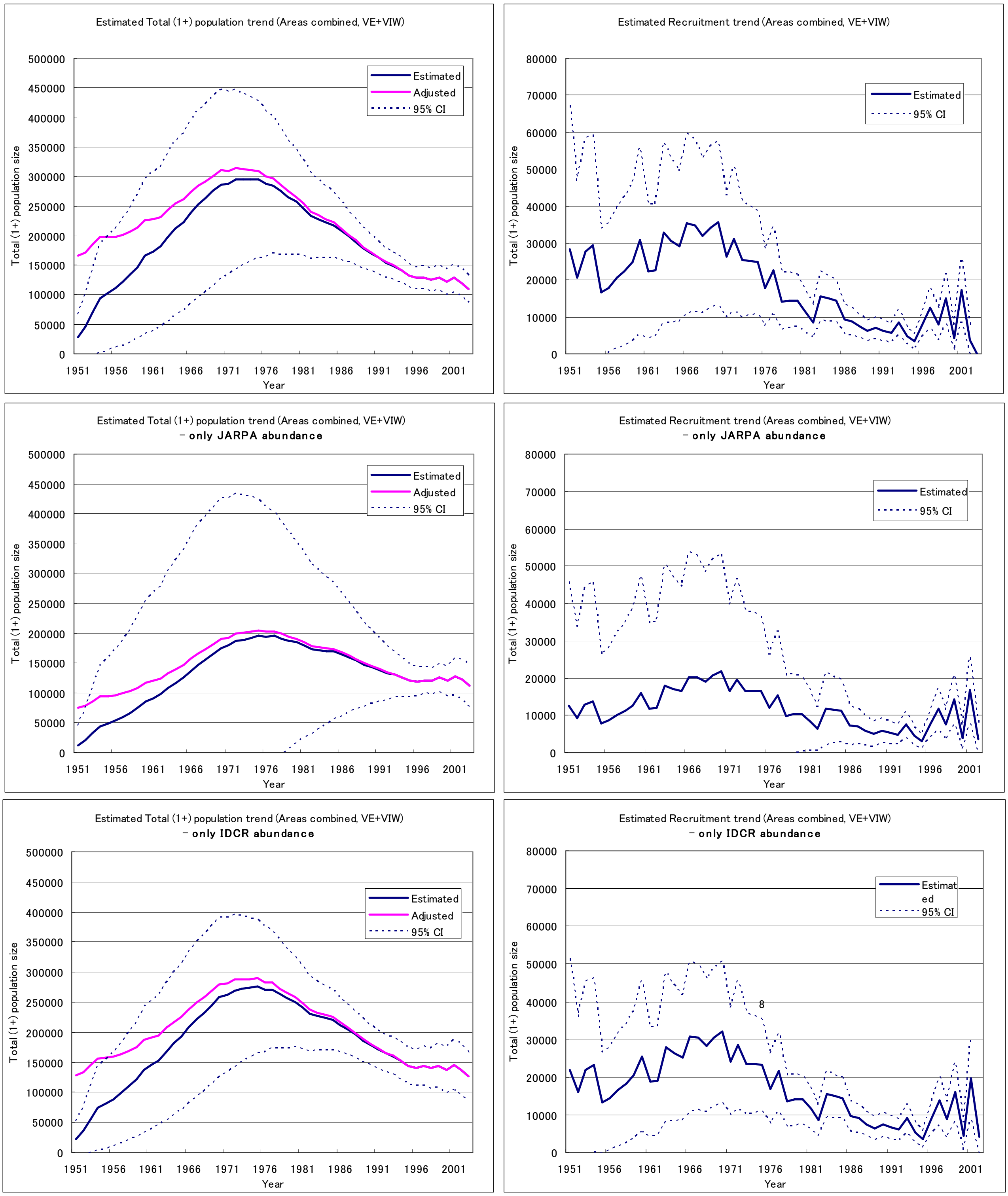


Figure 8b. Estimated total (1+) population and recruitment trend for the Area VE+VIW case (so-called “P-stock”) for three cases 1: both IDCR/SOWER and JARPA abundance estimates are fitted, 2: only JARPA abundance estimates are fitted and 3: only IDCR abundance estimates are fitted. The difference between the “estimated” and “adjusted” total population sizes is explained in Mori and Butterworth (2005).

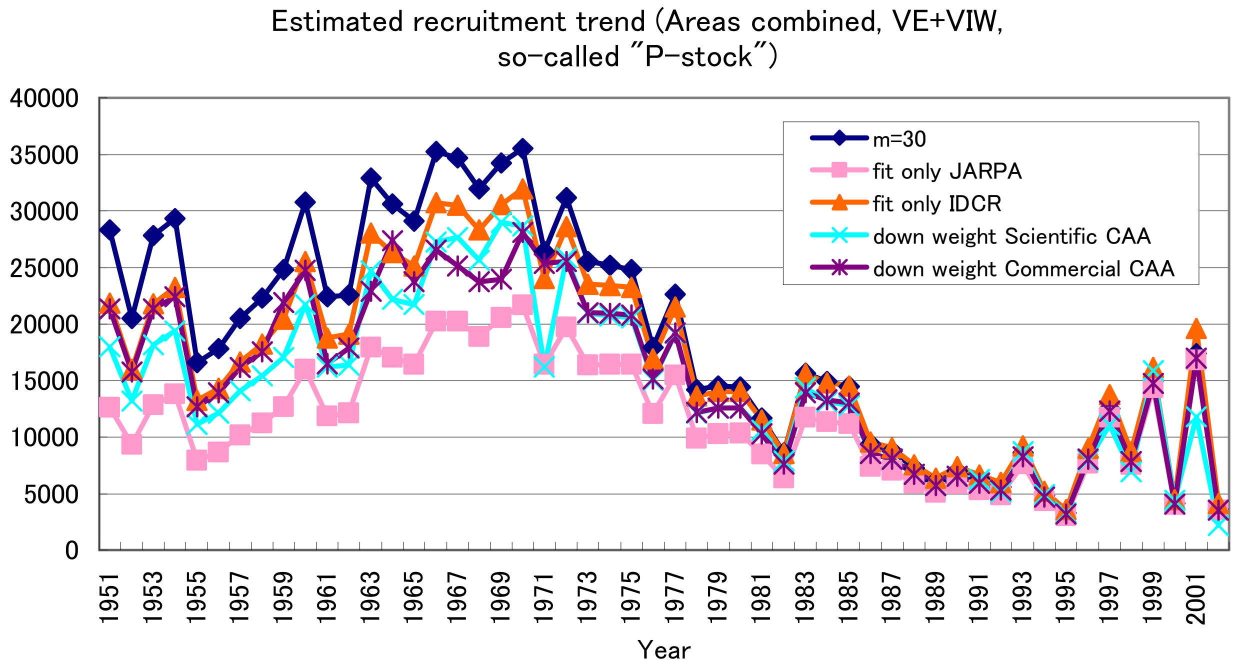


Figure 9. Estimated recruitment trend for the Areas VE+VIW combined assessment case (so-called "P-stock") for various sensitivities. Details of these sensitivity tests are given in the text.

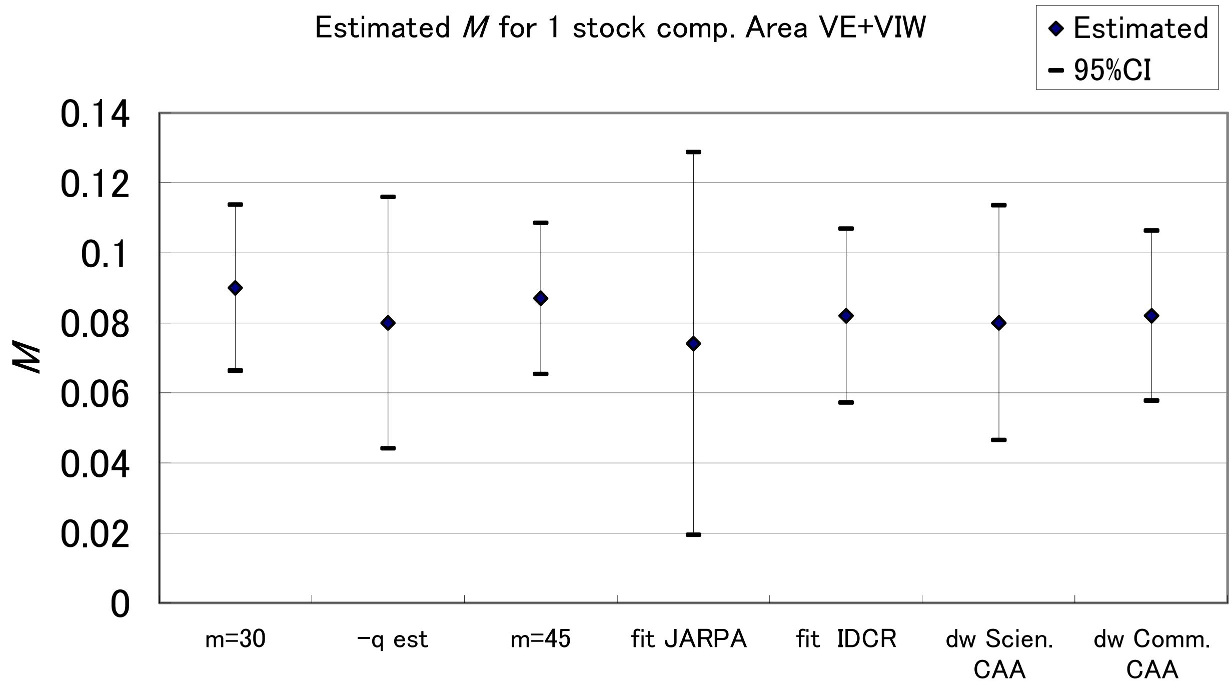


Figure 10. Estimated M for the Areas VE+VIW combined assessment case (so-called "P-stock") for various sensitivities. Details of these sensitivity tests are given in the text.

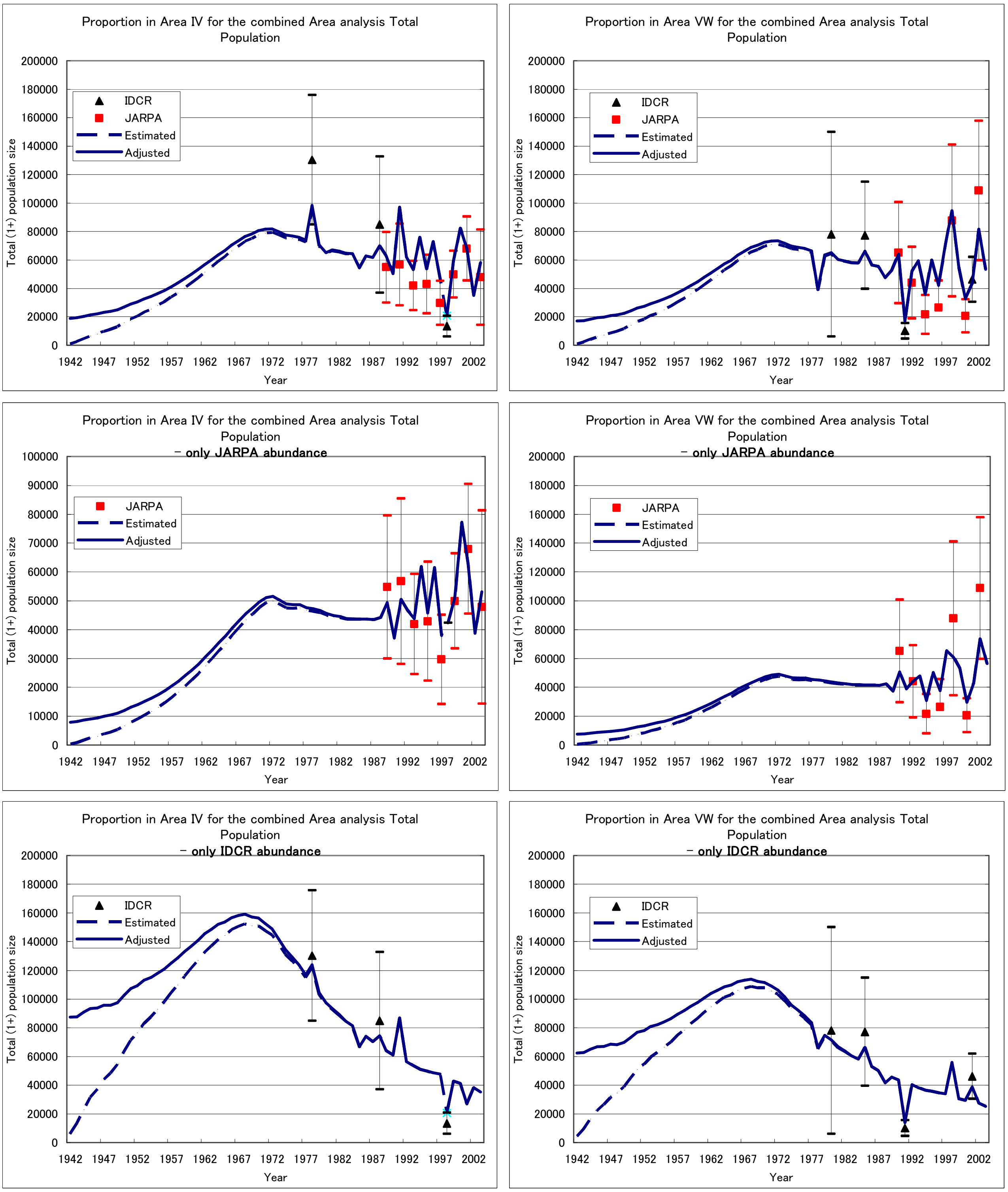


Figure11a. Fits of the ADAPT-VPA model to the total (1+) abundance estimates for Areas IV and VW separately for each Area for the Area IV+VW scenario for three cases 1: both IDCR/SOWER and JARPA abundance estimates are fitted, 2:only JARPA abundance estimates are fitted and 3: only IDCR abundance estimates are fitted. The abundance plots include the survey estimates of abundance together with their survey sampling estimated 95% confidence intervals. The difference between the “estimated” and “adjusted” total population sizes is explained in Mori and Butterworth (2005).

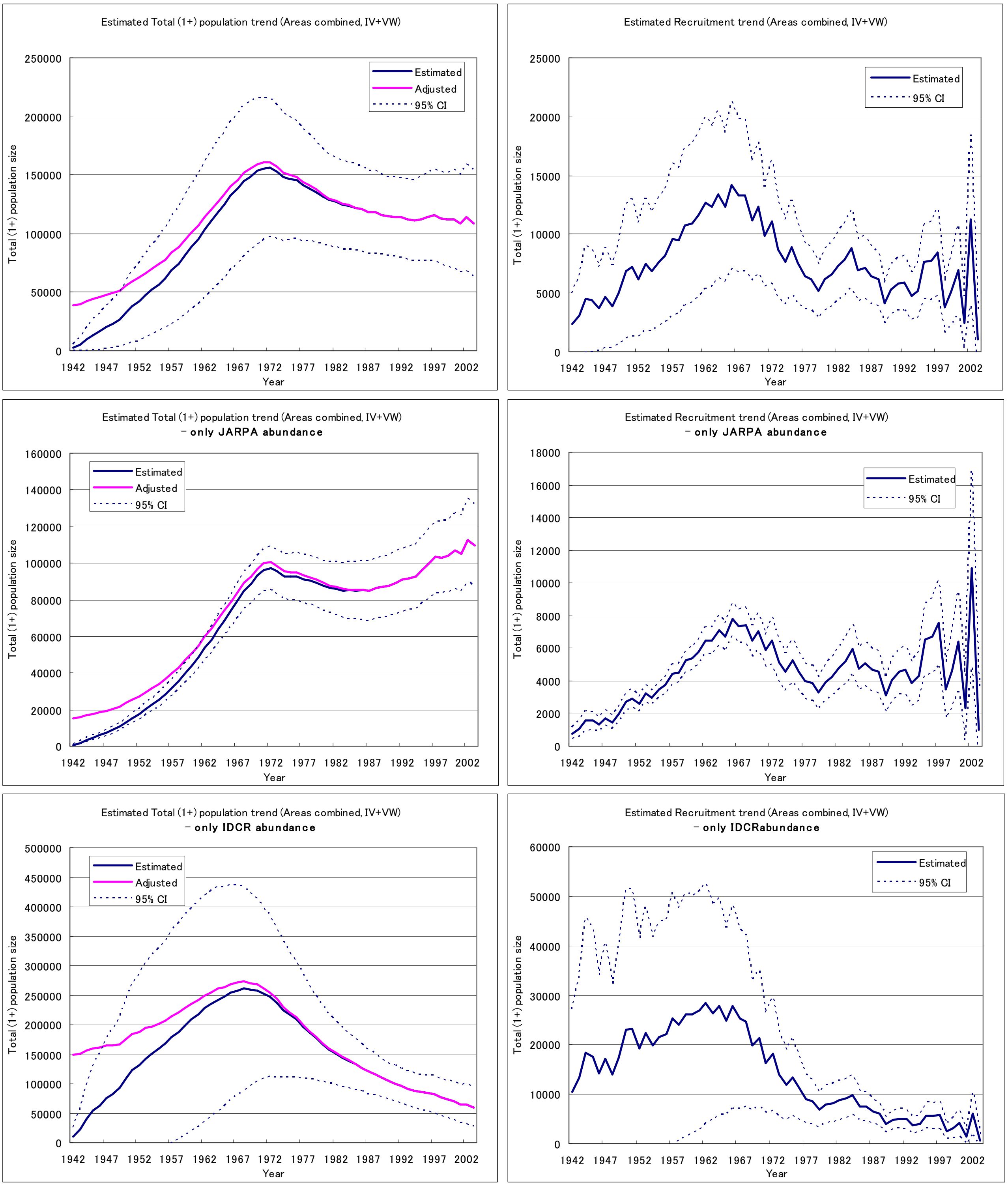


Figure 11b. Estimated total (1+) population and recruitment trend for the Area IV+VW case for three cases 1: both IDCR/SOWER and JARPA abundance estimates are fitted, 2: only JARPA abundance estimates are fitted and 3: only IDCR abundance estimates are fitted. The difference between the “estimated” and “adjusted” total population sizes is explained in Mori and Butterworth (2005).

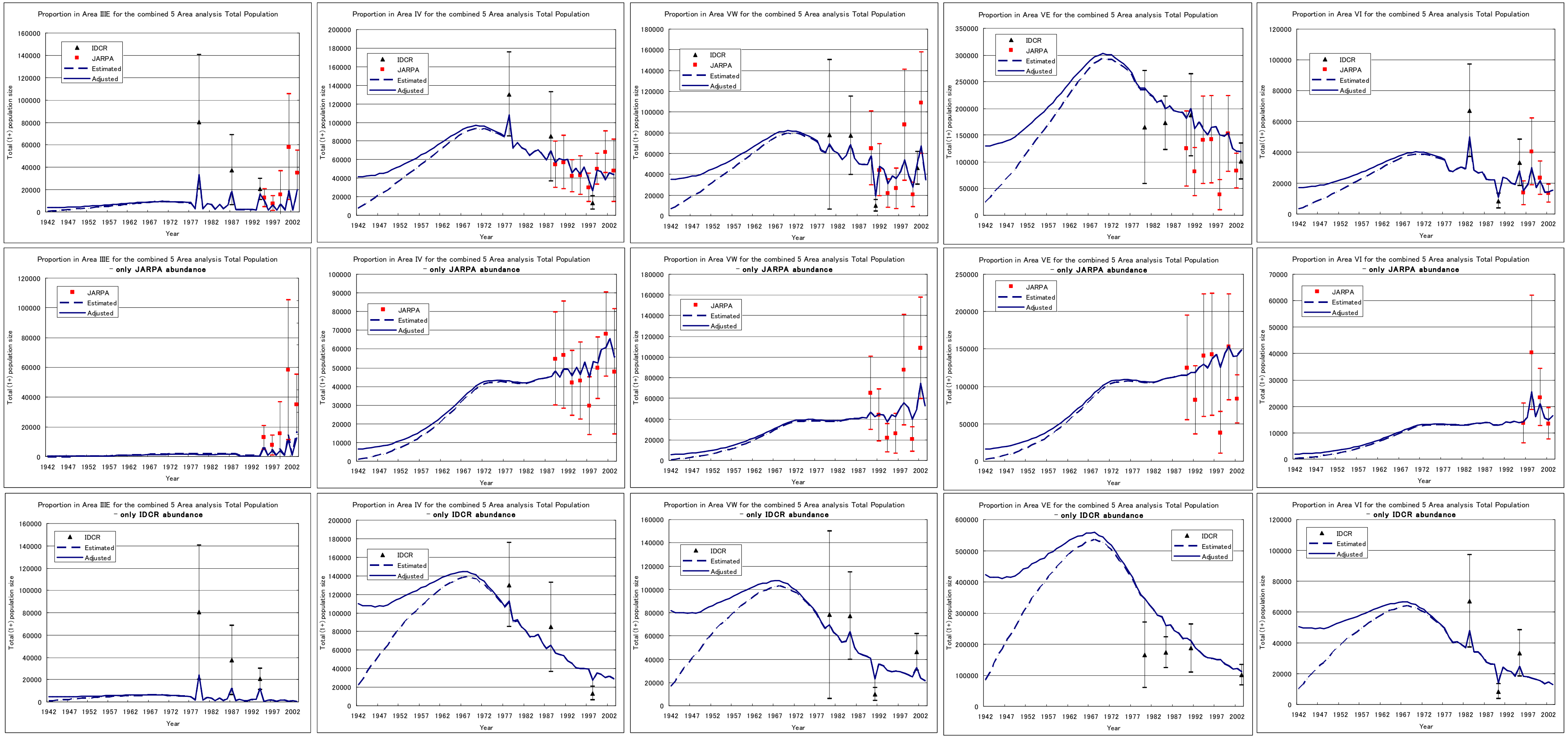


Figure12a. Fits of the ADAPT-VPA model to the total (1+) abundance estimates for Areas IIIIE to VIW separately for each Area for the Area IIIE+IV+VW+VE+VIW scenario for three cases 1: both IDCR/SOWER and JARPA abundance estimates are fitted, 2:only JARPA abundance estimates are fitted and 3: only IDCR abundance estimates are fitted. The abundance plots include the survey estimates of abundance together with their survey sampling estimated 95% confidence intervals. The difference between the "estimated" and "adjusted" total population sizes is explained in Mori and Butterworth (2005).

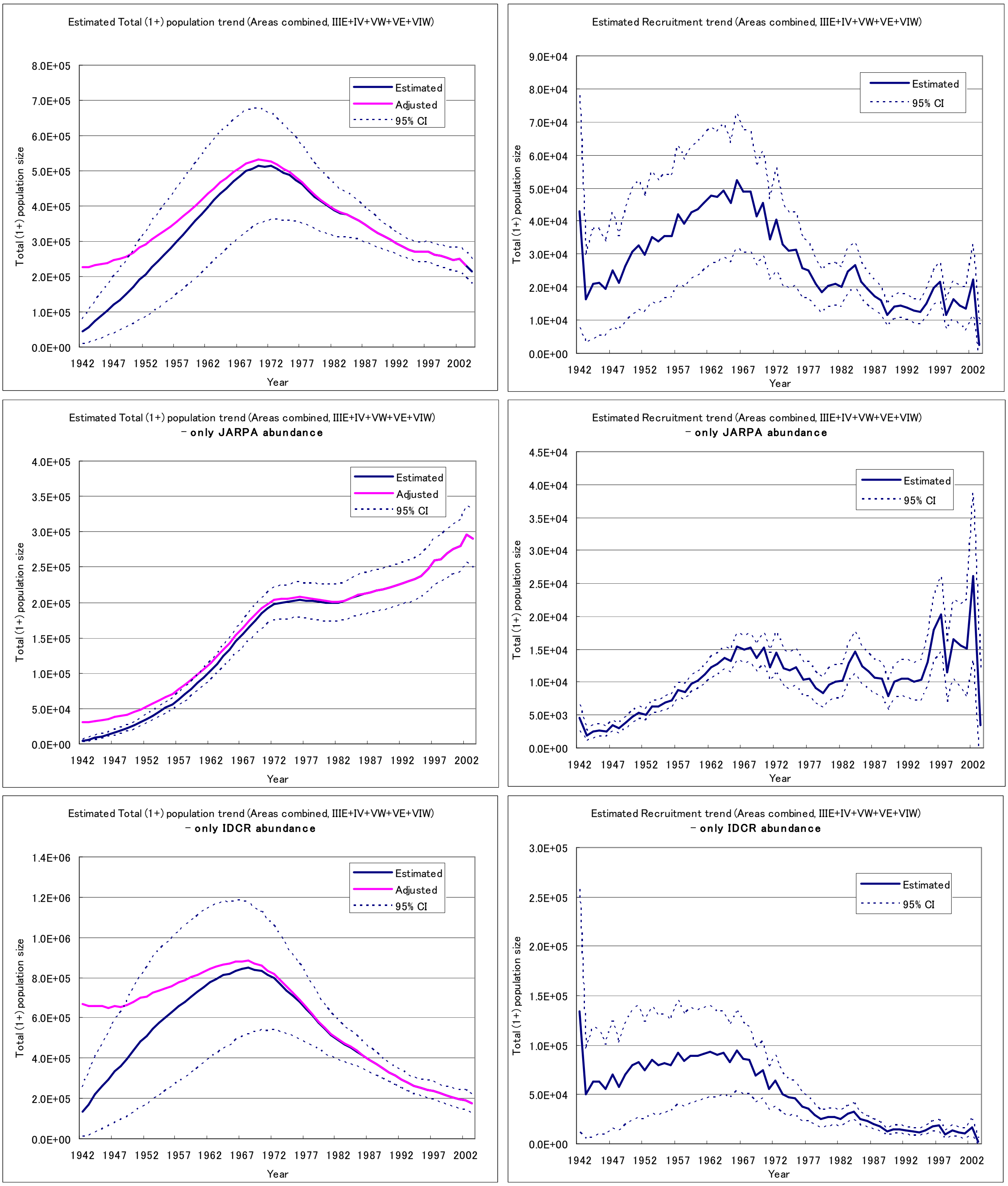
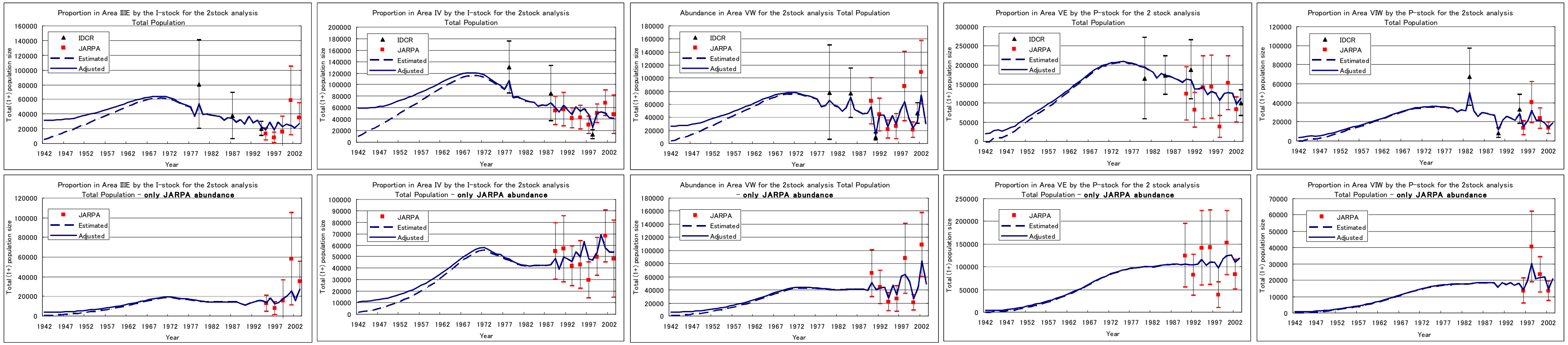


Figure 12b. Estimated total (1+) population and recruitment trend for the Area IIIE+IV+VW+VE+VIW case for three cases 1: both IDCR/SOWER and JARPA abundance estimates are fitted, 2: only JARPA abundance estimates are fitted and 3: only IDCR abundance estimates are fitted. The difference between the “estimated” and “adjusted” total population sizes is explained in Mori and Butterworth (2005).



Proportion in Area IIIE by the I-stock for the 2stock analysis Total Population

Proportion in Area IV by the I-stock for the 2stock analysis Total Population

Abundance in Area VW for the 2stock analysis Total Population

Proportion in Area VE by the P-stock for the 2 stock analysis Total Population

Proportion in Area VIW by the P-stock for the 2stock analysis Total Population

Proportion in Area IIIE by the I-stock for the 2stock analysis Total Population – **only JARPA abundance**

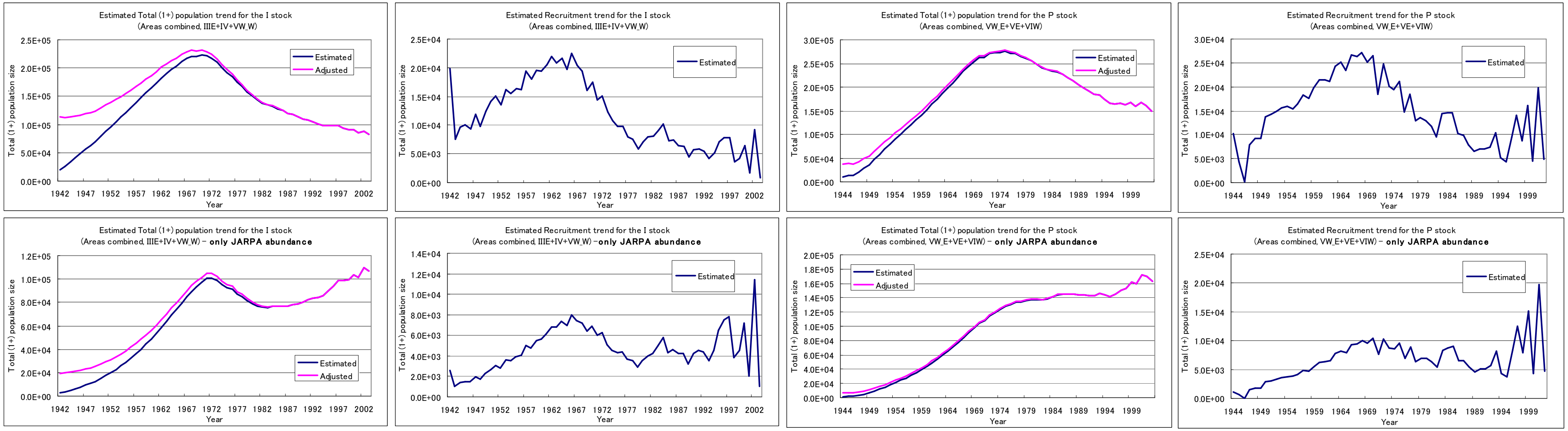
Proportion in Area IV by the I-stock for the 2stock analysis Total Population – **only JARPA abundance**

Abundance in Area VW for the 2stock analysis Total Population – **only JARPA abundance**

Proportion in Area VE by the P-stock for the 2 stock analysis Total Population – **only JARPA abundance**

Proportion in Area VIW by the P-stock for the 2stock analysis Total Population – **only JARPA abundance**

Figure13a. Fits of the ADAPT-VPA model to the total (1+) abundance estimates for I-stock (Areas IIIE, IV, and VW_W), and P-stock (VW_E, VE and VIW) separately for each Area for the two stock hypothesis with some mixing in Area VW. Two cases are shown 1: both IDCR/SOWER and JARPA abundance estimates are fitted, 2:only JARPA abundance estimates are fitted . The model did not converge when only IDCR/SOWER abundance estimates were fitted to the model due to lack of information on recent abundance estimates. The abundance plots include the survey estimates of abundance together with their survey sampling estimated 95% confidence intervals. The difference between the “estimated” and “adjusted” total population sizes is explained in Mori and Butterworth (2005).


Estimated Total (1+) population trend for the I stock (Areas combined, IIIE+IV+VW_W)

Estimated Recruitment trend for the I stock (Areas combined, IIIE+IV+VW_W)

Estimated Total (1+) population trend for the P stock (Areas combined, VW_E+VE+VIW)

Estimated Recruitment trend for the P stock (Areas combined, VW_E+VE+VIW)

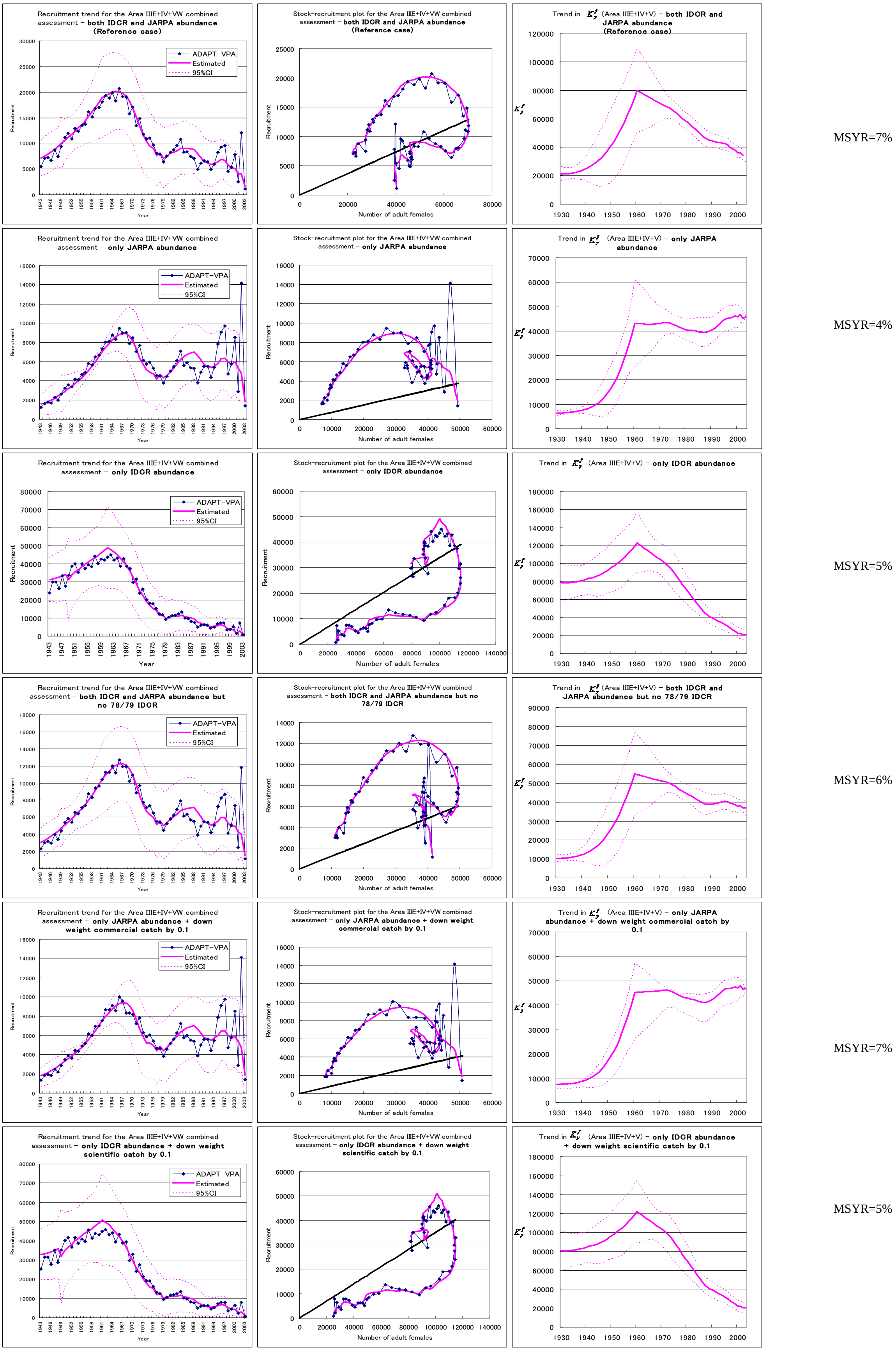
Estimated Total (1+) population trend for the I stock (Areas combined, IIIE+IV+VW_W) – **only JARPA abundance**

Estimated Recruitment trend for the I stock (Areas combined, IIIE+IV+VW_W) –**only JARPA abundance**

Estimated Total (1+) population trend for the P stock (Areas combined, VW_E+VE+VIW) – **only JARPA abundance**

Estimated Recruitment trend for the P stock (Areas combined, VW_E+VE+VIW) – **only JARPA abundance**

Figure 13b. Estimated total (1+) population and recruitment trend for the two stock hypothesis with some mixing in Area VW case for two cases 1: both IDCR/SOWER and JARPA abundance estimates are fitted, 2: only JARPA abundance estimates are fitted. The model did not converge when only IDCR/SOWER abundance estimates were fitted to the model due to lack of information on recent abundance estimates. The difference between the "estimated" and "adjusted" total population sizes is explained in Mori and Butterworth (2005).


Recruitment trend for the Area IIIE+IV+VW combined assessment – **both IDCR and JARPA abundance (Reference case)**

Stock-recruitment plot for the Area IIIE+IV+VW combined assessment – **both IDCR and JARPA abundance (Reference case)**

Trend in K^f_y (Area IIIE+IV+V) – **both IDCR and JARPA abundance (Reference case)**

Recruitment trend for the Area IIIE+IV+VW combined assessment – **only JARPA abundance**

Stock-recruitment plot for the Area IIIE+IV+VW combined assessment – **only JARPA abundance**

Trend in K^f_y (Area IIIE+IV+V) – **only JARPA abundance**

Recruitment trend for the Area IIIE+IV+VW combined assessment – **only IDCR abundance**

Stock-recruitment plot for the Area IIIE+IV+VW combined assessment – **only IDCR abundance**

Trend in K^f_y (Area IIIE+IV+V) – **only IDCR abundance**

Recruitment trend for the Area IIIE+IV+VW combined assessment – **both IDCR and JARPA abundance but no 78/79 IDCR**

Stock-recruitment plot for the Area IIIE+IV+VW combined assessment – **both IDCR and JARPA abundance but no 78/79 IDCR**

Trend in K^f_y (Area IIIE+IV+V) – **both IDCR and JARPA abundance but no 78/79 IDCR**

Recruitment trend for the Area IIIE+IV+VW combined assessment – **only JARPA abundance + down weight commercial catch by 0.1**

Stock-recruitment plot for the Area IIIE+IV+VW combined assessment – **only JARPA abundance + down weight commercial catch by 0.1**

Trend in K^f_y (Area IIIE+IV+V) – **only JARPA abundance + down weight commercial catch by 0.1**

Recruitment trend for the Area IIIE+IV+VW combined assessment – **only IDCR abundance + down weight scientific catch by 0.1**

Stock-recruitment plot for the Area IIIE+IV+VW combined assessment – **only IDCR abundance + down weight scientific catch by 0.1**

Trend in K^f_y (Area IIIE+IV+V) – **only IDCR abundance + down weight scientific catch by 0.1**

Figure 14. Fit of the model of equations (32)-(35) to the recruitment trend, the associated stock-recruit plot, and the estimated trend in carrying capacity of adult females over time for the Area IIIE+IV+VW combined assessment case (so-called “I-stock”) for the Reference case and various sensitivities. The straight lines on the stock-recruitment plots are “Replacement lines” for which the number of births and deaths are the same so that the population size remains unchanged.

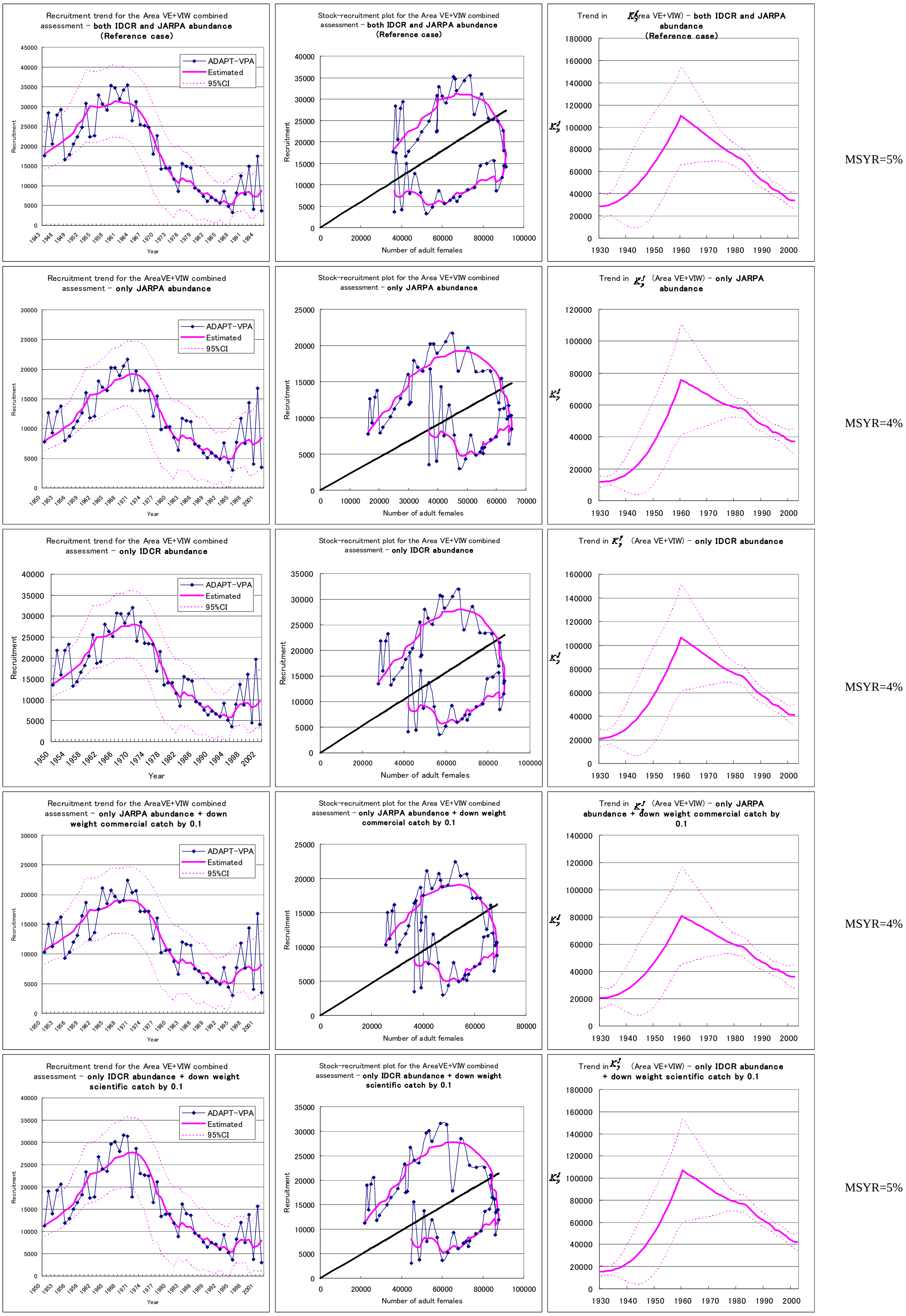


Figure 15 Fit of the model of equations (32) to (35) to the recruitment trend, the associated stock-recruit plot, and the estimated trend in carrying capacity of adult females over time for the Area VE+VIW combined assessment case (so-called “P-stock”) for the Reference case and various sensitivities. The straight lines on the stock-recruitment plots are “Replacement lines” for which the number of births and deaths are the same so that the population size remains unchanged.