# Assessment results for humpback breeding stocks D, E1 and Oceania following recommendations from SC 65a

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ABSTRACT

Following recommendations made at IWC 65a, 2013, a single-stock BSD (Breeding Stock D, West Australia) model has been run for a range of Antarctic catch boundaries, and some two-stock BSE1 (Breeding Stock E1, East Australia)+BSO (Breeding Stock Oceania) models have been explored. The single-stock BSD model excluded the Hedley *et al.* (2011) absolute abundance estimate from the model fits, and instead utilised an uninformative uniform prior on the log of the target abundance estimate. The minimum value for this prior was based on calculations by Hedley of a minimum absolute abundance indicated by the 2005-2008 survey (Hedley *et al.* 2011). These changes markedly improve the fit to the BSD relative abundance series. The two-stock models considered consist of one model with fixed Antarctic boundaries that allowed for a proportion of each of the BSE1 and BSO stocks to feed in a common feeding ground between 170°E and 170°W, and a second model in which there was no overlap between the two stocks, but a range of different Antarctic catch boundaries have been explored. Results of these models showed that (a) the BSE1 growth rate remained virtually at 0.106 yr$^{-1}$ (the demographic boundary imposed by the model), (b) fits to the BSE1 mark-recapture data were relatively poor and (c) the $N_{min}$ constraint remained problematic for BSO. Further two-stock runs, as well as a three-stock run, have not been included in this paper, but the authors aim to provide the results as an addendum to this paper at the meeting.

## INTRODUCTION

For the past few years, assessment models for the Southern Hemisphere humpback breeding stocks BSD (Western Australia), BSE1 (Eastern Australia) and BSO (Oceania) have been explored at the meetings of the IWC Scientific Committee. During this time various types of models have been run, including independent single-stock models, two-stock models (both for BSD+BSE1 and BSE1+BSO) as well as three-stock models allowing for neighbouring stocks to feed in overlapping Antarctic feeding grounds.

One major discussion point amongst the sub-committee on other Southern Hemisphere whale stocks has centred on an anomaly observed for BSD models, where the model-predicted population trajectory was unable to simultaneously fit an absolute abundance estimate for 2008(Hedley *et al.* 2011) as well as reflect the high growth rate suggested by the relative abundance series from Hedley *et al.* (2011). Discussions revealed that there was some uncertainty about the absolute abundance estimate (IWC 2013), so that it was decided that the estimate should not be used in the model fitting process. Some information on an absolute abundance is however still needed for the Bayesian estimation process (see section Bayesian estimation framework under Methods), and it was decided an uninformative uniform prior should be used, with a lower bound informed by further work that was to be carried out by Hedley.

Given the above considerations, and the fact that another major discussion point has been the issue of potential sub-structuring of the Oceania breeding stock, the sub-committee recommended that the following work be done inter-sessionally (IWC 2013):

1) A lower bound on the BSD abundance estimate should be obtained.
2) A single-stock model for BSD will be run for a range of choices of the Antarctic feeding ground catches between 120E and 150E.
3) Two stock BSE1-Oceania models (with further breeding stock division within Oceania) will be explored
4) If time permits after sufficient exploration of the models above, more complex options may be examined. These could include a three-stock model covering all of BSD, BSE1 and Oceania, together perhaps with more complex models for the dynamics of BSD.

Point (1) was undertaken by Hedley, who tentatively advised a value of 4900 with 95% CI [4100,7900] for surface available whales, and suggested a correction for surface availability of 0.3-0.4 (Hedley, *pers. commn*). Given this, a rounded value of 15000 has been assumed for this paper, and all the assessments presented for BSD use a uniform prior of U[ln15 000, ln40 000] for the log of the target abundance estimate for 2008 (see section

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Bayesian estimation framework under Methods). The single-stock models for Point (2) have been completed and are presented in this paper.

Several different variants of two-stock models were proposed and circulated to the inter-sessional email group. These consisted of BSE1-BSO two-stock models, and also some BSD -(BSE1+BSE2, i.e. Eastern Australia and New Caledonia) models. In this paper, results are presented for a selection of the BSE1- BSO models as a starting point for discussions and further runs to be undertaken at the meeting to address Point (3). It is hoped that results for the BSD -(BSE1+BSE2) models, as well as for a re-run of the three-stock model using the new treatment of the BSD absolute abundance estimate will be ready to be provided at the meeting as an addendum to this document.

Model descriptions for the single-stock BSD model and the two-stock BSE1 vs BSO models for which results are presented in this paper are given in Appendices B and C. Descriptions of the remaining models will follow in the addendum.

## DATA

### Historic catch data

There are two sets of historic catch data, both of which are available from Allison's database (C. Allison, *pers. comm*n):

i) Catches north of 40°S

These catches are given by location. Additionally there are some Russian catch data available by 10 degree longitude and latitude bands. The allocations of these catches to the breeding stocks considered in this assessment are described below.

*Breeding stock D*

Those labelled "Aust W" in the database have been allocated to BSD. Note that catches labelled "IndOcW" have been assumed to be associated with BSC. Russian catches taken between 80E and 130E have been allocated to BSD (a total of 120 catches).

*Breeding Stock E1and Oceania*

The catches for E1 and Oceania are given by landing station. Catches landed at LochTay, Tangalooma, Byron Bay and Rakiura have been allocated to BSE1. Catches landed at New Zealand, Kaikoura, Great Barrier Island, Whangamumu, Bay of Island, Norfolk Island, Tonga and Polynesia have been allocated to the Oceania breeding stock. Catches taken in the Cook Strait and Tory Channel have been split equally between BSE1 and Oceania.

The resulting catch series are given in Table A. 1 of the Appendix.

ii) Catches south of 40°S

These catches are given for 10 degree longitude bands, as shown in Table A. 2.

### Abundance and trend data

The data used in this assessment are listed in the Appendix. A summary is given below of which data where used for the base case and which were used for independent consistency checks, as recommended at IWC 64. Note that not all the data listed in the Appendix have been explored in these assessments.

**Table 1:** Summary of the assessment input data

| Breeding ground data | | Reference Case | Sensitivity | Consistency Check |
|---|---|---|---|---|
| *Breeding Stock D* | | | | |
| Absolute abundance | Hedley *et al.* (2011) | | | X[2] |
| Relative abundance | Hedley *et al.* (2011) | X | | |
| Relative abundance | Bannister and Hedley (2001) | | X | |
| Relative abundance | Chittleborough (1965) | | | X |
| Min number of haplotypes | Olavarria *et al.* (2007) | X | | |
| *Breeding Stock E1* | | | | |
| Absolute abundance | Noad *et al.* (2011) | X | | |
| Absolute abundance | Paton *et al.* (2011) | | | X |
| Relative abundance | Noad *et al.* (2011) | X | | |
| Relative abundance | Chittleborough (1965) | | | X |
| Relative abundance | Forestell *et al.* (2011) | | | |
| Mark-recapture (photo-ID) | Forestell *et al.* (2011) | | | X |
| Mark-recapture (genetic) | Jackson *et al.* (2012) | | | X |
| Mark-recapture (photo-ID) | Paton *et al.* (2011) | | | X |
| Min number of haplotypes | Olavarria *et al.* (2007); Valsecchi *et al.* (2010) | X | | |
| *Oceania breeding stock* | | | | |
| Mark-recapture (genetic) | Constantine *et al.* (2012) | X | | |
| Absolute abundance | Constantine *et al.* (2012)[3] | | | X |
| Mark-recapture (genetic) | Jackson *et al.* (2012) | | | X |
| Min number of haplotypes | Olavarria *et al.* (2007) | X | | |
| *Data informing interchange* | | | | |
| Mark-recapture (photo-ID) | Pacific Whale Organisation – D and E1 | | | |
| Mark-recapture (genetic) | Anderson *et al.*(2007) – D and E1 | | | |
| Mark-recapture (genetic) | Jackson *et al.* (2012) – E1 and Oceania | | | |
| **Feeding ground data** | | Reference Case | Sensitivity | Consistency Check |
| Relative abundance | Matsuoka *et al.* (2011) | | X | X |
| Relative abundance | Branch (2011) | | X | X |
| Mixing proportions | Pastene *et al.* (2013) | | | |

**METHODS**

**Population dynamics**

The population dynamics are given by the following equation:

$$N_{y+1}^i = N_y^i + r^i N_y^i \left( 1 - \left( \frac{N_y^i}{K^i} \right)^\mu \right) - C_y^i \qquad i \in \{D, E1, Oceania\} \qquad (1)$$

where

$N_y^i$      is the number of whales in the breeding population *i* at the start of year *y*,

$r^i$      is the intrinsic growth rate (the maximum per capita the population can achieve when its size is very low) of breeding population *i*,

$K^i$      is the carrying capacity or pristine population level of breeding population *i*,

$\mu$      is the "degree of compensation" parameter; this is set at 2.39, which fixes the level at which MSY is achieved at MSYL = 0.6*K*, as conventionally assumed by the IWC SC, and

$C_y^i$      is the total catch (in terms of breeding population *i* animals) in year *y*.

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[2] The Hedley *et al.* (2011) absolute abundance estimate was used as the reference case in 2013, but is now only used as a consistency check given the uncertainty around the value.

[3] The absolute abundance estimate derived from the mark recapture data is used to set bounds on the uniform prior for the log target abundance estimate in the SIR process. The original mark recapture data are used in the likelihood function itself.

**Bayesian estimation framework**

*Priors*

Prior distributions are defined for the following parameters:

i) $\quad r^i \sim U[0, 0.106]$ [4]

ii) $\quad \ln \tilde{N}_{target}^{i,obs} \sim U[\ln N_{target}^{i,obs} - 4CV, \ln N_{target}^{i,obs} + 4CV]$ [5]

The target abundance estimate is fitted to the model-predicted number of whales for breeding population $i$.

The uninformative $r$ prior is bounded by zero (negative rates of growth are biologically implausible) and 0.106 (this corresponds to the maximum growth rate for the species agreed by the IWC Scientific Committee (IWC, 2007)). The prior distribution from which target abundance estimate $\tilde{N}_{target}^{i,obs}$ is drawn at random is uniform on a natural logarithmic scale. The upper and lower bounds, whose only purpose is to render the computations more efficient, are set by the CV of the abundance estimate multiplied by four.

Using the randomly drawn vector of values of $\tilde{N}_{target}^{i,obs}$ and $r^i$, a downhill simplex method of minimization is used to calculate $K^i$ such that the model estimate of $N_{target}^{i}$ is identical to the randomly drawn value $\tilde{N}_{target}^{i,obs}$.

For each simulation, using the $r^i$ and calculated $K^i$ values, the available data are used to assign a likelihood to that particular combination. Details for calculating the components of the negative log likelihood are given below.

Priors for the mixing proportion parameters which come into play in the two- and three-stock models, and described in Appendix B.

*Likelihood function*

*Absolute abundance data*

Given an absolute abundance estimate, $N_{target}^{obs}$, this is assumed to be log-normally distributed with the log of the estimate as the mean and the CV as the standard deviation[6]. Thus the negative log likelihood contribution is:

$$\frac{1}{2\sigma^2}\left(\ln N_{target}^{obs} - \ln N_{target}\right)^2 \tag{2}$$

where

$\quad N_{target}^{obs}$ $\quad$ is the absolute abundance estimate obtained from observations,

$\quad N_{target}$ $\quad$ is the model-estimated population size for the year of the abundance estimate, and

$\quad \sigma^2$ $\quad$ is the variance of $\ln N_{target}^{obs}$..

*Relative abundance data*

These estimates are given in a series spanning several years. Each year has a relative abundance index $I_y$, obtained from observations. It is assumed that this index is log-normally distributed about its expected value:

$$I_y = qN_y e^{\varepsilon_y} \tag{3}$$

where

$\quad I_y$ $\quad$ is the relative abundance estimate for year $y$,

$\quad q$ $\quad$ is a constant of proportionality[7],

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[4] Note that an importance function was used for $r^{EI}$ to improve sampling efficiency. Details are given later.

[5] Note that for BSD, $\ln \tilde{N}_{target}^{BSD,obs} \sim U[\ln 15000, \ln 40000]$

[6] If $N$ is assumed to be log-normally distributed, then $\ln N$ is normally distributed with some mean $\mu$ and standard deviation $\sigma$. The median value of $N$ is then $e^{\mu}$ while the CV of $N$ is given by $\sqrt{e^{\sigma^2} - 1}$. Since the CV of $N$ is relatively small, $\sigma$ has been approximated here by the value of the CV of $N$.

[7] When plotting the relative abundance series along with the model-predicted median population values to assess how good the fit is, the relative abundance series each need to be scaled by a factor of $q$. In the SIR process, once the original sample is

$N_y$          is the model estimate of observed population size at the start of year $y$, and

$\varepsilon_y$          is from $N(0,\sigma^2)$ (see Equation (4) below).

The $\sigma$ parameter is the residual standard deviation, which is estimated in the fitting procedure by its maximum likelihood value:

$$\hat{\sigma} = \sqrt{1/\bar{n}\sum_y \left(\ln I_y - \ln q - \ln N_y\right)^2} \tag{4}$$

where

$\bar{n}$          is the number of data points in the series, and

$q$          is a constant of proportionality, estimated by its maximum likelihood value:

$$\ln \hat{q} = 1/\bar{n}\sum_y \left(\ln I_y - \ln N_y\right) \tag{5}$$

The negative log-likelihood component for the relative abundance data is given by:

$$\bar{n}\ln\sigma + \frac{1}{2\sigma^2}\sum_y \left(\ln I_y - \ln q - \ln N_y\right)^2 \tag{6}$$

In the Bayesian context, $q$ and $\sigma$ are "nuisance parameters, i.e. parameters that need to be estimated but are not of interest themselves (McAllister *et al.,* 1994). Walters and Ludwig (1994) show that the above approach is essentially a shortcut to avoid integrating over the prior distributions parameters and corresponds to the assumption that the $q$ prior is uniformly distributed in log-space, and that the $\sigma$ prior is proportional to $\sigma^{-3}$.

*Mark recapture data*

These data are given in the form a matrix showing counts of animals that were seen in a specific year and re-seen in a subsequent year. The method for incorporating this information into the likelihood is given below.

The capture-recapture data give:

$n_y$, the number of animals captured in year $y$, and

$m_{y,y'}$, the number of animals captured in year $y$ that were recaptured in year $y'$.

If $p_y$ is the probability that an animal is seen in a region in year $y$, then the number of animals captured in year $y$ is given by:

$$n_y = p_y N_y \tag{7}$$

where $N_y$ is the total (1+) population. The model predicted number of animals captured in year $y$ that were recaptured in year $y'$ is given by:

$$\hat{m}_{y,y'} = p_y p_{y'} N_y e^{-M(y'-y)} \tag{8}$$

where $M$ is the natural mortality rate (set here to equal 0.03 yr$^{-1}$ as recommended by the IWC SC).

The probability of a model-predicted $\hat{m}_{y,y'}$, given the observed $m_{y,y'}$, is determined assuming a Poisson distribution[8], with the associated likelihood contribution given by:

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resampled (based on the weights calculated using the desired input data), the likelihood components for all the data sets (even those not used in the final likelihood calculation) can be computed for each of the $n_2$ resampled parameter combination of [$r$, $lnN_{target}$]. The likelihood component of each relative abundance series will have an associated $q$ value, giving $n_2$ $q$ values (representing samples from the posterior distribution of $q$), from which the median value can be computed. This value is then used to scale the relative abundance series for plotting, as has been done in the figures of this document.

[8] The equations given here imply a multinomial distribution. However, because the annual capture probabilities are so small, the Poisson distribution is an adequate and convenient approximation.

$$\frac{\left(\hat{m}_{y,y'}\right)^{m_{y,y'}}}{\hat{m}_{y,y'}!}e^{-\hat{m}_{y,y'}} \tag{9}$$

Finally the component for the negative of the log-likelihood for capture-recapture data is then given by:

$$\sum_{y=y_o}^{y_f-1}\sum_{y'=y+1}^{y_f}[-m_{y,y'}\ln\hat{m}_{y,y'}+\hat{m}_{y,y'}] \tag{10}$$

where $y_0$ is the first year of captures and $y_f$ is the last year of recaptures.

Note that when compiling the capture-recapture matrices, if an animal is re-seen a second time, the first resighting is treated as a new sighting that is first re-seen at the second resighting.

### *SIR*

The negative log likelihood is then converted into a likelihood value ($L$). The integration of the prior distributions of the parameters and the likelihood function then essentially follows the Sampling-Importance-Resampling (SIR) algorithm presented by Rubin (1988). For a vector of parameter values $\theta_i$, the likelihood of the data associated with this vector of parameters ($L$) as described above is calculated and stored as $\tilde{L}$. This process is repeated until an initial sample of $n_1$ $\theta_i$s is generated.

This sample is then resampled with replacement $n_2$ times with probability equal to weight $w_j$, where:

$$w_j=\frac{\tilde{L}\left(\theta_j/data\right)}{\sum_{j=1}^{n1}\tilde{L}\left(\theta_j/data\right)} \tag{11}$$

The resample is thus a random sample of size $n_2$ from the joint posterior distribution of the parameters (Rubin, 1988).

### *Importance function for BSE1*

The trend data for BSE1 (Noad *et al.*, 2011) are highly informative, and as such high $r^{EI}$ values have a much higher likelihood associated with them and have a much better chance of being resampled. Since $r^{EI}$ is sampled from a uniform prior on the interval [0,0.106], small values of $r^{EI}$ will form a substantial proportion of the initial sample of $n_I$, even though they are not likely to be chosen in the resampling process. This leads to sampling inefficiency and a high number of duplicates (where the same high $r$ values are sampled repeatedly). A very large initial sample has to then be drawn in order to generate enough samples with high $r$ values to be able to resample without a high number of duplicates. In order to increase the sampling efficiency, an importance function was used. This function increases the likelihood of sampling high $r^{EI}$ values and reduces the number of essentially wasted low $r$ values in the sample. To counter the fact that the resulting distribution of the $n_I$ values of $r^{EI}$ sampled is no longer uniform as required by the uniform prior distribution, the final likelihood values are weighted up in the same proportion as the probability of picking a particular $r^{EI}$ in the initial sample was weighted down.

The importance function used is shown in Figure 1 below. Given this function, the likelihood associated with any sample containing an $r^{EI}$ valued between 0 and 0.05 is up-weighted by a factor of 20, the likelihood associated with any sample containing an $r^{EI}$ valued between 0.05 and 0.07 is up-weighted by a factor of 5, etc.
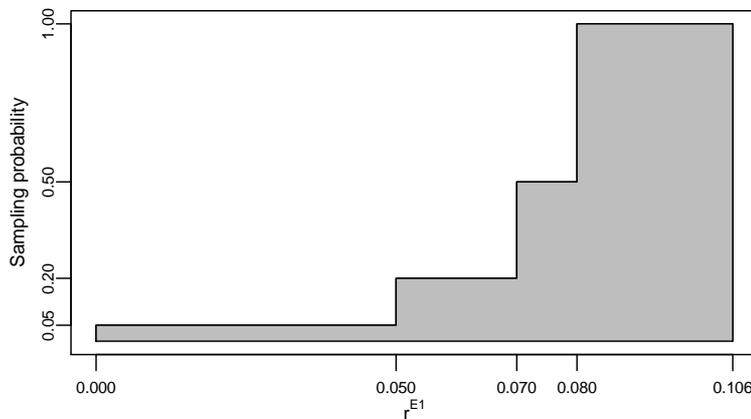
**Figure 1:** Importance function used when sampling for $r^{E1}$. The horizontal axis shows the step values of $r^{E1}$ at which the importance function increases, and the vertical axis shows the probability of accepting an $r^{E1}$ sample from a particular range. In other words, if a value between 0 and 0.05 is drawn from the uniform prior, it has a 95% chance of being discarded.

### $N_{min}$ constraints

The assumption for these assessments is that given a minimum number of haplotypes, $h$, for a specific region, the minimum population size for that region is given by $3*h$. This offers a constraint below which values the model estimated population trajectory must not go. A penalty is added to the negative log likelihood to ensure that these constraints are not violated.

## RESULTS AND DISCUSSION

### Single-stock BSD model

The model structure considered is indicated diagrammatically in Appendix B. Posterior median values for key model parameters are given in Table 2 for the range of Antarctic catch boundaries that were tested. Figure 2 shows the corresponding plots of the trajectories and fits to the relative and absolute abundance data. Figure 3 allows for comparison of the trajectories resulting from the different Antarctic catch boundaries.

The most noteworthy point from these assessments is that by excluding the Hedley *et al.* (2011) absolute abundance estimate from the model fits, and by utilising an uninformative uniform prior on the log of the target abundance estimate, the fits to the relative abundance series are good and a marked improvement of what could be achieved when the absolute abundance estimate was included in the model fitting process.

Moving of the Antarctic catch boundaries has relatively little impact on the results. It is however evident that the model-predicted median $N_{2008}$ value is closest to the Hedley *et al.* (2011) absolute abundance estimate for 2008 when the Antarctic catch boundaries are such that the largest possible number of catches is allocated to BSD.

### Two-stock BSE1+BSO models

Posterior median values for the first of the two-stock BSE1+BSO models (see the E1_O#1 diagram in Appendix C) are given in Table 3. The corresponding plots of the trajectories are shown in Figure 4 and Figure 5. Figure 4 shows only the fits to data that have been included in the model fitting process, while Figure 5 shows fits to all data as consistency checks. In Table 3, parameters of particular interest are the interchange proportions $\beta_{EO}$ and $\beta_{OE}$. As can be seen in the table, the probability intervals for these values are fairly large, suggesting that there is relatively little information to inform on these parameters. It is clear from Table 4 and Figure 4b that the $N_{min}$ constraint for BSO continues to be problematic, as the results are visibly different when the $N_{min}$ constraint is excluded. This is a point that should be considered at the meeting and possible approaches to address the issue should be discussed. It should also be noted that the estimated growth rate for BSE1 continues to be high and virtually at the demographic boundary imposed by the model, resulting in a very narrow probability envelope for the BSE1 population trajectory. The importance function for $r^{E1}$ utilised in these assessments could possibly be adjusted to further increase the efficiency of model runs that involve BSE1.

Figure 5(c) - Figure 5 (j) show the fits to various mark-recapture data. For these cumulative resightings plots, the most important points to consider are the last in the series. The resightings are accumulated over the years and the last points in particular should lie within the probability envelope provided by the model estimate. It is noteworthy that in general the BSE1 model results do not agree well with the mark-recapture data. The cumulative resightings observed are substantially higher than the model estimates, suggesting that the population size estimate by the model is too large. It should be born in mind however, that these comparisons are shown as a reality check only and that these data are not included in the model fits. Fits/comparisons of the BSO population to the various mark-recapture data are considerably better. It is interesting to note that while the fit to the Jackson *et al.* (2011) sexes-combined data is good, the model seems to underestimate the male population size and overestimate the female population size, suggesting that the 50:50 ratio between male and females assumed in the model may not be appropriate.

Posterior median values and the corresponding plots of the trajectories for the second of the two-stock BSE1+BSO models (see the E1_O#2 diagram n Appendix C) are given in Table 5 and Figure 6. It is evident from Figure 6 that increasing the catches allocated to a particular stock has the effect of increasing the estimated carrying capacity for that stock, as can be expected since a higher initial population is needed to sustain the greater number of catches. Table 6 lists the negative log-likelihood components for the different Antarctic catch boundaries. It can be seen from this table that the shifting of the Antarctic boundaries has a greater impact (in likelihood terms) on BSE1 than BSO, and that the case where the largest number of catches are allocated to BSE1 (case c) yields the best likelihood values. The issue of where to set the Antarctic catch boundaries should be discussed further at IWC 65b.

## ACKNOWLEDGEMENTS

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**Table 2:** Posterior median values of key model parameters are given with their 90% probability intervals for the **single-stock BSD** model runs (see Appendix B). For each run, the Antartic feeding ground catches from the indicated longitude bands were allocated to BSD. Column heading Rel I gives the standard deviation of the residuals for the fit to the Hedley *et al.* (2011) relative abundance series, Rel II for the fit to the Bannister and Hedley (2001) relative abundance series, Rel III for the Chittleborough (1965) relative abundance series and Rel IV for the Matsuoka *et al.* (2011) relative abundance series. The models were fit to the Hedley *et al.* (2011) and Bannister and Hedley (2001) relative abundance series only. Note that the model was not fit to the Hedley *et al.* (2011) absolute abundance estimate of 28830 (95% CI = 23 710-40100) (Hedley *et al.* 2011) for 2008, although the model-predicted $N_{2008}$ value has been given in the table for comparison purposes. Instead, the models utilise a uniform prior on the log of the 2008 abundance estimate ranging from 15000 to 40000, where the choice for the lower bound has been informed by analyses of the survey data by Hedley (*pers. commn*).

| BSD | r | | K | | $N_{min}$ | | $N_{2008}$ | | $N_{2012}/K$ | | $N_{2040}/K$ | | RelI | RelII | RelIII | RelIV |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| a) 70E-120E | 0.089 | [0.046,0.104] | 21381 | [19660,30193] | 872 | [437,4994] | 19181 | [17801,24209] | 0.899 | [0.709,0.978] | 1 | [0.981,1.000] | 0.274 | 0.208 | 0.285 | 0.568 |
| b) 70E-130E | 0.089 | [0.049,0.104] | 22622 | [20880,30932] | 824 | [424,3737] | 19803 | [18203,23881] | 0.874 | [0.689,0.974] | 1 | [0.985,1.000] | 0.264 | 0.207 | 0.275 | 0.558 |
| c) 70E-140E | 0.090 | [0.049,0.105] | 23994 | [22347,32896] | 783 | [390,4042] | 20693 | [18583,25072] | 0.858 | [0.657,0.978] | 1 | [0.981,1.000] | 0.257 | 0.205 | 0.265 | 0.554 |
| d) 70E-150E | 0.092 | [0.055,0.105] | 28095 | [26529,35240] | 762 | [372,2883] | 22739 | [19553,27807] | 0.801 | [0.628,0.969] | 1 | [0.984,1.000] | 0.243 | 0.204 | 0.319 | 0.539 |

**Table 3:** Posterior median values of key model parameters are given with their 90% probability intervals for the **first two-stock BSE1+BSO** model run (see the BSE1+BSO #1 diagram in Appendix C). The Antarctic catch boundaries are not varied. The model assumes that a (time-invariant) proportion of each stock feeds in a common feeding ground between 170°e and 170°W, and catches in this area of overlap are allocated according to the number of whales present. The model is fit to the Noad *et al.* (2011) absolute abundance estimate and the Noad *et al.* (2011) relative abundance series for BSE1, and to the Constantine *et al.* (2012) mark-recapture data for BSO.

| | r | | K | | $\beta_{EO}, \beta_{OE}$ | | $N_{min}$ | | $N_{2012}/K$ | | $N_{2040}/K$ | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| BSE1 | 0.105 | [0.103,0.106] | 30241 | [27718,32110] | 0.314 | [0.042,0.477] | 229 | [203,262] | 0.553 | [0.500,0.626] | 0.999 | [0.999,1.000] |
| BSO | 0.029 | [0.003,0.049] | 13498 | [10342,19458] | 0.267 | [0.030,0.508] | 1018 | [511,2508] | 0.255 | [0.149,0.369] | 0.532 | [0.162,0.871] |

**Table 4:** Results for the **two-stock BSE1+BSO** model run as for Table 3, except with no $N_{min}$ constraint in the model fit.

| | r | | K | | $\beta_{EO}, \beta_{OE}$ | | $N_{min}$ | | $N_{2012}/K$ | | $N_{2040}/K$ | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| BSE1 | 0.105 | [0.103,0.106] | 30691 | [27903,32209] | 0.334 | [0.062,0.477] | 229 | [203,267] | 0.548 | [0.494,0.620] | 0.999 | [0.999,1.000] |
| BSO | 0.049 | [0.008,0.098] | 11386 | [8708,18361] | 0.236 | [0.023,0.475] | 512 | [107,2165] | 0.345 | [0.161,0.572] | 0.851 | [0.204,0.999] |

**Table 5:** Posterior median values of key model parameters are given with their 90% probability intervals for the **second two-stock BSE1+BSO** model run (see the BSE1+BSO #2 diagram in Appendix C). This model aims to explore the effect of moving the boundaries for the Antarctic catches. Run (a) serves as a reference case. Runs (b) and (c) test two extremes for the boundary between BSE1 and BSO, and runs (d) and (e) shift the western boundary of BSE1 and the eastern boundary of BSO. The models are fit to the Noad *et al.* (2011) absolute abundance estimate and the Noad *et al.* (2011) relative abundance series for BSE1, and to the Constantine *et al.* (2012) mark-recapture data for BSO.

| BSE1 | $r$ | | $K$ | | $N_{min}$ | | $N_{2012}/K$ | | $N_{2040}/K$ | |
|---|---|---|---|---|---|---|---|---|---|---|
| a) 120E:170E:110W | 0.105 | [0.103,0.106] | 26824 | [26788,26939] | 0.009 | [0.008,0.010] | 0.610 | [0.558,0.666] | 1.000 | [0.999,1.000] |
| b) 120E:150E:110W | 0.105 | [0.102,0.106] | 14305 | [14266,14445] | 0.016 | [0.014,0.020] | 0.889 | [0.856,0.927] | 1.000 | [1.000,1.000] |
| c) 120E:170W:110W | 0.105 | [0.103,0.106] | 32020 | [31975,32150] | 0.007 | [0.006,0.008] | 0.526 | [0.480,0.579] | 0.999 | [0.999,1.000] |
| d) 130E:170E:120W | 0.105 | [0.103,0.106] | 25548 | [25513,25656] | 0.009 | [0.008,0.010] | 0.635 | [0.577,0.695] | 1.000 | [1.000,1.000] |
| e) 110E:170E:100W | 0.105 | [0.104,0.106] | 28740 | [28702,28860] | 0.008 | [0.007,0.009] | 0.578 | [0.524,0.631] | 1.000 | [0.999,1.000] |
| BSO | $r$ | | $K$ | | $N_{min}$ | | $N_{2012}/K$ | | $N_{2040}/K$ | |
| a) 120E:170E:110W | 0.030 | [0.005,0.050] | 17245 | [15473,22116] | 0.057 | [0.032,0.108] | 0.200 | [0.130,0.263] | 0.432 | [0.150,0.773] |
| b) 120E:150E:110W | 0.030 | [0.003,0.050] | 31915 | [29550,38553] | 0.031 | [0.017,0.065] | 0.110 | [0.074,0.139] | 0.249 | [0.082,0.495] |
| c) 120E:170W:110W | 0.030 | [0.005,0.051] | 10649 | [ 9438,14339] | 0.092 | [0.051,0.168] | 0.324 | [0.203,0.425] | 0.649 | [0.229,0.919] |
| d) 130E:170E:120W | 0.030 | [0.003,0.050] | 17064 | [15289,22406] | 0.058 | [0.032,0.110] | 0.202 | [0.126,0.267] | 0.437 | [0.140,0.773] |
| e) 110E:170E:100W | 0.031 | [0.005,0.051] | 17244 | [15553,22418] | 0.055 | [0.031,0.107] | 0.202 | [0.130,0.263] | 0.444 | [0.147,0.772] |

**Table 6:** Median negative log-likelihood components for the **second two-stock BSE1+BSO** model. Note that the models were fit to the Noad *et al.* (2011) absolute abundance estimate and the Noad *et al.* (2011) relative abundance series for BSE1, and to the Constantine *et al.* (2012) mark-recapture data for BSO. The other relative abundance and mark-recapture data indicated were not used in fitting the model, but their negative log-likelihoods for the model as fit to the other data are shown. The columns corresponding to the data used in the model fit have been highlighted in grey. In each column, the row corresponding to the best likelihood value (i.e. minimum negative log-likelihood) is in bold.

| BSE1 | Abs (Noad *et al.*) | Rel (Noad *et al.*) | Rel (Chittleborough 1965) | Rel (Matsuoka *et a.* 2011) | MR males (Jackson *et al.* 2012) | MR females (Jackson *et al.* 2012) | MR (Forrestell *et al.* 2011) |
|---|---|---|---|---|---|---|---|
| a) 120E:170E:110W | 0.270 | -40.163 | 3.556 | -0.217 | -3.285 | 2.337 | -1248.350 |
| b) 120E:150E:110W | 4.705 | -28.979 | 3.984 | -0.160 | -2.742 | 3.131 | -1223.511 |
| c) 120E:170W:110W | **0.246** | **-41.036** | 3.721 | **-0.220** | **-3.393** | **2.193** | **-1250.236** |
| d) 130E:170E:120W | 0.296 | -39.740 | 3.619 | -0.215 | -3.235 | 2.398 | -1247.308 |
| e) 110E:170E:100W | 0.247 | -40.613 | **3.312** | -0.218 | -3.320 | 2.284 | -1249.328 |

| BSO | Abs (Constantine *et al.* 2012) | MR (Constantine *et al.* 2012) | MR males (Jackson *et al.* 2012) | MR females (Jackson *et al.* 2012) | Total negative log-likelihood for data components used in model fit |
|---|---|---|---|---|---|
| a) 120E:170E:110W | 6.699 | -58.885 | -16.863 | **3.877** | -98.324 |
| b) 120E:150E:110W | **6.615** | -58.829 | -16.929 | 3.890 | -82.829 |
| c) 120E:170W:110W | 6.762 | **-58.904** | -16.876 | 3.880 | **-99.284** |
| d) 130E:170E:120W | 6.643 | -58.832 | **-16.955** | 3.919 | -97.844 |
| e) 110E:170E:100W | 6.696 | -58.892 | -16.865 | 3.875 | -98.791 |

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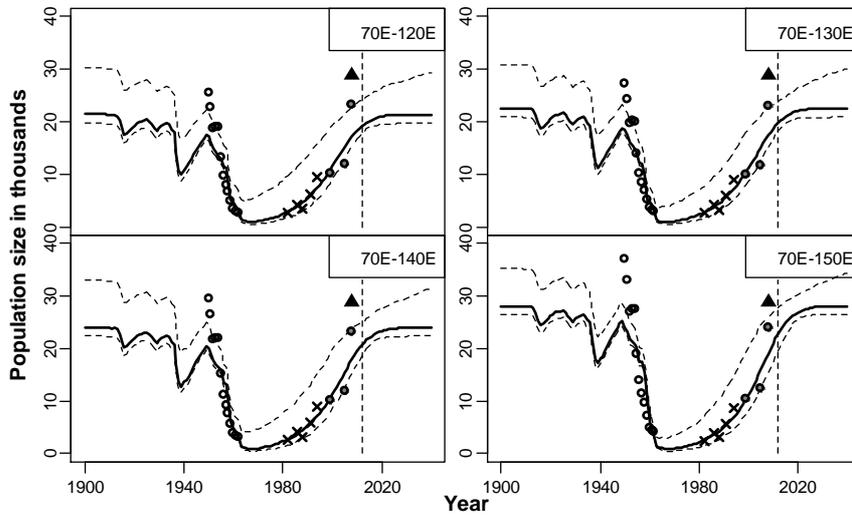
**Figure 2:** Posterior median population trajectories are given for the **single-stock BSD model**, showing the trajectories and the 90% probability envelopes for a range of Antarctic catch boundaries. Plots show fits to the Chittleborough (1965) relative abundance series (open circles), the Bannister and Hedley (2001) relative abundance series (crosses), the Hedley *et al.* (2011) relative abundance series (grey circles) as well as the Hedley *et al.* (2011) absolute abundance estimate (black triangle). In all cases the model was fit to the Hedley *et al.* (2011) and the Bannister & Hedley (2001) relative abundance series. The Chittleborough (1965) and Hedley *et al.* (2011) absolute abundance estimate are shown as consistency checks. The trajectories to the right of the vertical dashed 2012 line show projections into the future under the assumption of zero catch.
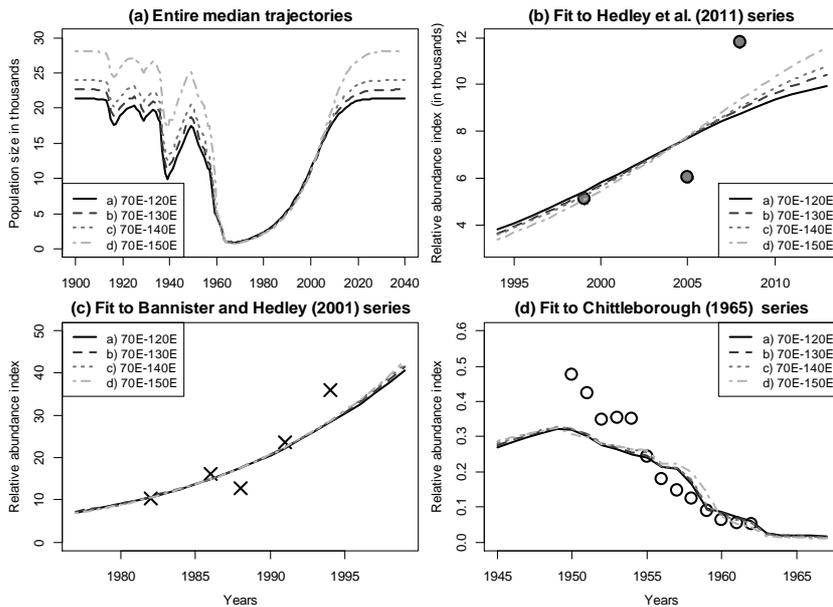


**Figure 3:** Plots showing comparisons of the results for the different Antarctic catch boundaries for the **single-stock BSD** model. Panel (a) shows the median population trajectories, while (b)-(d) show the fits to the relative abundance series. Note that the model has not been fit to the Chittleborough (1965) data, and the fits in Figure (d) have been shown as a reality check only.

**(a) BSE1**

**(b) BSO**

**(c) BSO - Constantine et al. (2012)**
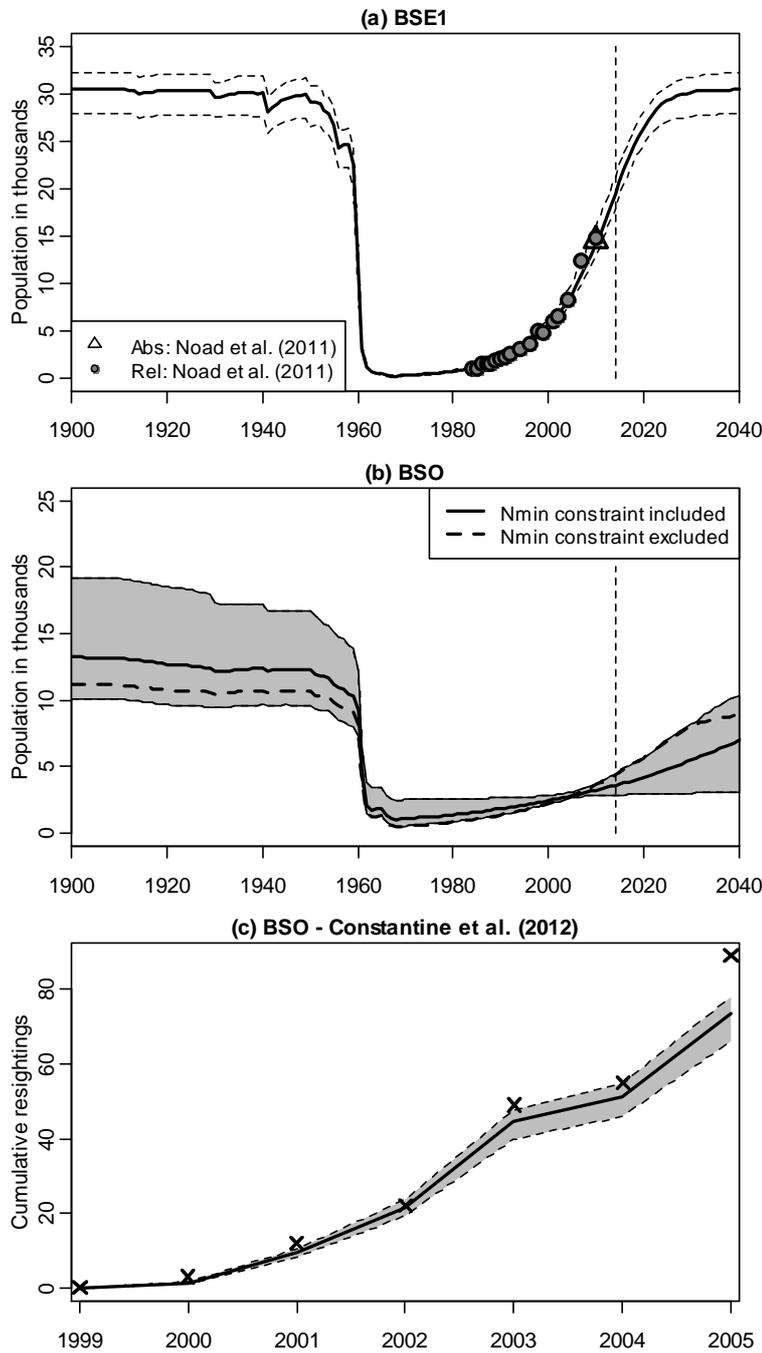
**Figure 4:** Figure 4a and b show the posterior median population trajectories and 90% probability envelopes for BSE1 and BSO for the **first two-stock BSE1+BSO** model (see the E1_O#2 diagram in Appendix C). In Figure 4b, the solid line indicates the trajectory when the $N_{min}$ constraint for BSO has been included, while the dashed line shows the case where it has been excluded. The model is fit to the Noad *et al.* (2011) absolute abundance estimate and the Noad *et al.* (2011) relative abundance series for BSE1 (fits shown in Figure 4a), and to the Constantine *et al.* (2012) mark-recapture data for BSO (Figure 4c). In Figure 4c, the cumulative observed re-sightings are marked by X's. The median estimates are shown by the thick line and their 90% probability envelope is indicated by the shaded region.
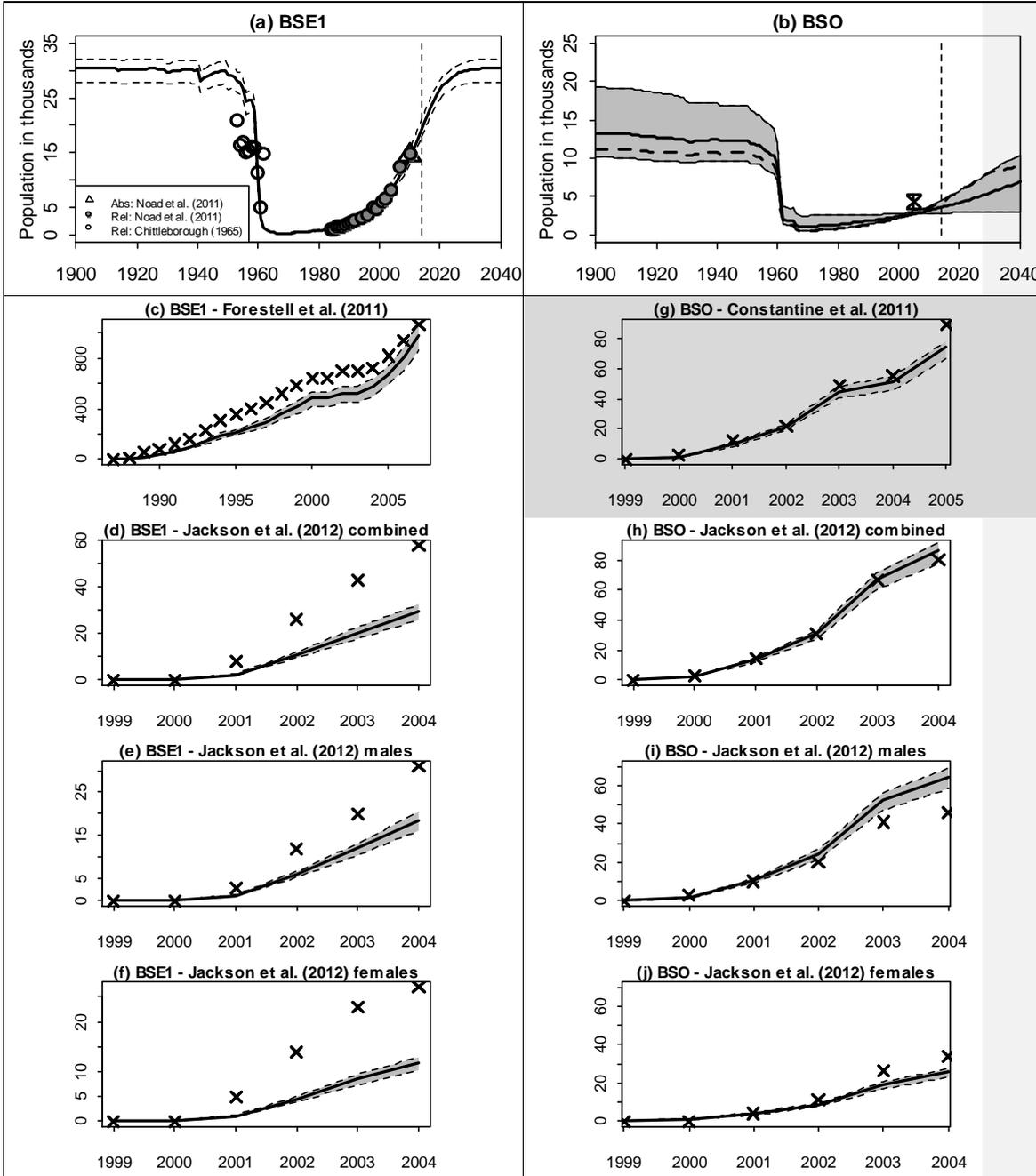
**Figure 5:** Figure 5a is a repeat of Figure 4a, except with the Chittleborough (1965) series included in the plot as a consistency check. Similarly, Figure 5b is a repeat of Figure 4b, with the fit to the Constantine *et al.* (2012) absolute abundance estimate shown as a consistency check. Figures (c)-(j) show fits to various mark recapture data. Note that for the mark-recapture data, only the BSO Constantine *et al.* (2012) data have been used in the model fit, and Figure 5g has therefore been highlighted with grey shading to emphasise this. The other mark-recapture plots are shown here only as consistency checks.

**(a) BSE1**

Abs: Noad et al. (2011)
Rel: Noad et al. (2011)
Rel: Chittleborough (1965)

Population size in thousands

**(b) BSO**

Population in thousands

**(c) BSE1**

Population size in thousands

Shift in longitudinal boundaries
a) ~ 120E ~ | ~ 170E ~ | ~ 110W ~
b) ~ 120E ~ | 150E ~ ~ | ~ 110W ~
c) ~ 120E ~ | ~ ~170W | ~ 110W ~
d) ~ ~ 130E | ~ 170E ~ | 120W ~ ~
e) 110E ~ ~ | ~ 170E ~ | ~ ~ 100W

**(d) BSO**

Population in thousands

Shift in longitudinal boundaries
a) ~ 120E ~ | ~ 170E ~ | ~ 110W ~
b) ~ 120E ~ | 150E ~ ~ | ~ 110W ~
c) ~ 120E ~ | ~ ~170W | ~ 110W ~
d) ~ ~ 130E | ~ 170E ~ | 120W ~ ~
e) 110E ~ ~ | ~ 170E ~ | ~ ~ 100W

**Figure 6:** Posterior median population trajectories for BSE1 and BSO for the **second two-stock BSE1+BSO** model (see the E1_O#2 diagram in Appendix C). Figures (a) and (b) show the median trajectory as well as the 90% probability envelope for the reference case Antarctic boundary positioning of 120E:170E:110W. Figures (c) and (d) contrast the median population trajectories for different Antarctic catch boundaries. Note that the positioning of the labels in the legend give a representation of the positions of the Antarctic catch boundaries.

**APPENDIX A: CATCH, ABDUNANCE AND TREND DATA**

**Table A. 1:** Historic catches taken north of 40°S from Allison's database (C.Allison, *pers. commn*). Note that for the assessments in this paper, the Cook Strait catches have been split equally between the East Australia and Oceania stocks.

| Year | BSD | BSE1 | Oceania | Cook Strait | Year | BSD | BSE1 | Oceania | Cook Strait |
|------|-----|------|---------|-------------|------|-----|------|---------|-------------|
| 1890 | 0 | 0 | 8 | 0 | 1935 | 0 | 0 | 0 | 57 |
| 1891 | 0 | 0 | 8 | 0 | 1936 | 3076 | 0 | 0 | 69 |
| 1892 | 0 | 0 | 8 | 0 | 1937 | 3250 | 0 | 0 | 55 |
| 1893 | 0 | 0 | 8 | 0 | 1938 | 917 | 0 | 0 | 75 |
| 1894 | 0 | 0 | 8 | 0 | 1939 | 0 | 0 | 0 | 80 |
| 1895 | 0 | 0 | 8 | 0 | 1940 | 0 | 0 | 0 | 107 |
| 1896 | 0 | 0 | 8 | 0 | 1941 | 0 | 0 | 0 | 86 |
| 1897 | 0 | 0 | 8 | 0 | 1942 | 0 | 0 | 0 | 71 |
| 1898 | 0 | 0 | 8 | 0 | 1943 | 0 | 0 | 0 | 90 |
| 1899 | 0 | 0 | 8 | 0 | 1944 | 0 | 0 | 0 | 88 |
| 1900 | 0 | 0 | 8 | 0 | 1945 | 0 | 0 | 0 | 107 |
| 1901 | 0 | 0 | 8 | 0 | 1946 | 0 | 0 | 0 | 110 |
| 1902 | 0 | 0 | 8 | 0 | 1947 | 2 | 0 | 0 | 101 |
| 1903 | 0 | 0 | 8 | 0 | 1948 | 4 | 0 | 0 | 92 |
| 1904 | 0 | 0 | 8 | 0 | 1949 | 190 | 0 | 3 | 141 |
| 1905 | 0 | 0 | 8 | 0 | 1950 | 388 | 0 | 0 | 79 |
| 1906 | 0 | 0 | 8 | 0 | 1951 | 1224 | 0 | 0 | 111 |
| 1907 | 0 | 0 | 8 | 0 | 1952 | 1187 | 600 | 0 | 121 |
| 1908 | 0 | 0 | 8 | 0 | 1953 | 1300 | 700 | 0 | 109 |
| 1909 | 0 | 0 | 16 | 0 | 1954 | 1320 | 718 | 0 | 180 |
| 1910 | 0 | 0 | 41 | 36 | 1955 | 1126 | 720 | 0 | 112 |
| 1911 | 0 | 0 | 41 | 36 | 1956 | 1119 | 720 | 166 | 127 |
| 1912 | 234 | 30 | 27 | 36 | 1957 | 1120 | 721 | 165 | 155 |
| 1913 | 993 | 348 | 56 | 36 | 1958 | 967 | 720 | 136 | 183 |
| 1914 | 1968 | 0 | 57 | 36 | 1959 | 700 | 810 | 270 | 214 |
| 1915 | 1297 | 0 | 70 | 36 | 1960 | 545 | 810 | 321 | 226 |
| 1916 | 388 | 0 | 25 | 57 | 1961 | 580 | 731 | 211 | 55 |
| 1917 | 0 | 0 | 58 | 36 | 1962 | 548.2 | 173 | 12 | 24 |
| 1918 | 0 | 0 | 50 | 40 | 1963 | 87 | 0 | 0 | 9 |
| 1919 | 0 | 0 | 72 | 47 | 1964 | 2 | 0 | 0 | 0 |
| 1920 | 0 | 0 | 64 | 43 | 1965 | 75.8 | 0 | 0 | 0 |
| 1921 | 0 | 0 | 55 | 34 | 1966 | 30 | 0 | 0 | 0 |
| 1922 | 155 | 0 | 40 | 17 | 1967 | 12 | 0 | 0 | 0 |
| 1923 | 166 | 0 | 62 | 17 | 1968 | 0 | 0 | 0 | 0 |
| 1924 | 0 | 0 | 55 | 52 | 1969 | 0 | 0 | 0 | 0 |
| 1925 | 669 | 0 | 48 | 48 | 1970 | 0 | 0 | 0 | 0 |
| 1926 | 735 | 0 | 35 | 43 | 1971 | 0 | 0 | 0 | 0 |
| 1927 | 996 | 0 | 74 | 53 | 1972 | 0 | 0 | 0 | 0 |
| 1928 | 1035 | 0 | 50 | 55 | 1973 | 0 | 0 | 3 | 0 |
| 1929 | 0 | 0 | 53 | 49 | 1974 | 0 | 0 | 4 | 0 |
| 1930 | 0 | 0 | 31 | 47 | 1975 | 0 | 0 | 8 | 0 |
| 1931 | 0 | 0 | 48 | 61 | 1976 | 0 | 0 | 4 | 0 |
| 1932 | 0 | 0 | 0 | 18 | 1977 | 0 | 0 | 4 | 0 |
| 1933 | 0 | 0 | 3 | 41 | 1978 | 0 | 0 | 11 | 0 |
| 1934 | 0 | 0 | 0 | 52 | **Total** | **28406** | **7801** | **2601** | **4060** |

**Table A. 2:** Historic catches taken south of 40°S from Allison's database (C.Allison, *pers. commn*), given in 10 degree longitude bands.

| Year | 60-69E | 70-79E | 80-89E | 90-99E | 100-109E | 110-119E | 120-129E | 130-139E | 140-149E | 150-159E | 160-169E | 170-180E | 180-170W | 169-160W | 159-150W | 149-140W | 139-130W | 129-120W | 119-110W | 109-100W |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 1908 | 217 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| 1909 | 118 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| 1910 | 83 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| 1911 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| 1912 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| 1913 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| 1914 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| 1915 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| 1916 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| 1917 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| 1918 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| 1919 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| 1920 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| 1921 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| 1922 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| 1923 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| 1924 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| 1925 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| 1926 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 82 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| 1927 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 16 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| 1928 | 11 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 17 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| 1929 | 11 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 775 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| 1930 | 3 | 1 | 16 | 4 | 3 | 0 | 1 | 0 | 32 | 49 | 3 | 55 | 96 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| 1931 | 0 | 109 | 51 | 1 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| 1932 | 2 | 1 | 38 | 41 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| 1933 | 20 | 81 | 457 | 43 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| 1934 | 9 | 83 | 964 | 266 | 22 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| 1935 | 0 | 1 | 744 | 196 | 0 | 0 | 0 | 0 | 4 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| 1936 | 0 | 15 | 597 | 755 | 68 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| 1937 | 1 | 56 | 337 | 125 | 188 | 129 | 32 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| 1938 | 0 | 0 | 0 | 173 | 482 | 180 | 24 | 24 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| 1939 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| 1940 | 0 | 0 | 0 | 0 | 0 | 0 | 342 | 342 | 342 | 342 | 342 | 342 | 342 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |

| Year | 60-69E | 70-79E | 80-89E | 90-99E | 100-109E | 110-119E | 120-129E | 130-139E | 140-149E | 150-159E | 160-169E | 170-180E | 180-170W | 169-160W | 159-150W | 149-140W | 139-130W | 129-120W | 119-110W | 109-100W |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 1941 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| 1942 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| 1943 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| 1944 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| 1945 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| 1946 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| 1947 | 0 | 1 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| 1948 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| 1949 | 0 | 0 | 516 | 48 | 101 | 10 | 109 | 30 | 760 | 118 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| 1950 | 0 | 5 | 351 | 599 | 160 | 0 | 0 | 0 | 0 | 0 | 0 | 85 | 86 | 316 | 0 | 0 | 1 | 0 | 0 | 0 |
| 1951 | 0 | 104 | 268 | 0 | 358 | 170 | 232 | 0 | 1 | 0 | 66 | 103 | 189 | 37 | 0 | 0 | 1 | 0 | 0 | 0 |
| 1952 | 1 | 2 | 0 | 190 | 0 | 0 | 0 | 0 | 0 | 0 | 166 | 216 | 135 | 13 | 0 | 0 | 0 | 0 | 0 | 0 |
| 1953 | 0 | 0 | 0 | 259 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 14 | 136 | 0 | 0 | 0 | 0 | 0 | 0 |
| 1954 | 0 | 0 | 0 | 20 | 6 | 0 | 0 | 2 | 0 | 749 | 5 | 17 | 167 | 269 | 69 | 2 | 0 | 0 | 0 | 0 |
| 1955 | 0 | 111 | 274 | 162 | 110 | 508 | 411 | 769 | 416 | 777 | 0 | 0 | 0 | 278 | 56 | 0 | 0 | 0 | 0 | 0 |
| 1956 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 7 | 3 | 27 | 39 |
| 1957 | 3 | 67.3 | 510.2 | 977.8 | 339.5 | 12 | 0 | 30 | 19 | 38 | 133 | 0 | 0 | 0 | 35 | 27 | 29 | 76 | 31 | 0 |
| 1958 | 9.8 | 287.5 | 1214 | 652 | 240 | 1275.9 | 882.1 | 104.7 | 157.1 | 185.7 | 525.8 | 209.4 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| 1959 | 5.2 | 6.4 | 16.9 | 91.1 | 97.7 | 41 | 44.8 | 1043.5 | 4057.1 | 3673 | 2228.5 | 998.7 | 317.8 | 112.8 | 73.2 | 106.8 | 73.2 | 73.2 | 74.1 | 7 |
| 1960 | 2 | 49.6 | 54.2 | 77.6 | 295.5 | 171.3 | 71 | 163.7 | 742.3 | 1184.3 | 3703.8 | 2630.2 | 740 | 962.5 | 565.3 | 508.3 | 428.6 | 292.9 | 0 | 0 |
| 1961 | 0 | 2 | 33 | 145 | 63 | 120 | 14 | 14 | 61 | 436 | 581 | 342 | 123 | 226 | 1010 | 401 | 452 | 189 | 54 | 44 |
| 1962 | 21 | 99 | 151 | 906 | 417 | 118.2 | 58.2 | 18.2 | 35.4 | 39.7 | 302.2 | 9.2 | 10 | 49.5 | 87.7 | 66.1 | 63.5 | 18.1 | 18.1 | 24.4 |
| 1963 | 46 | 33.2 | 105.4 | 116 | 34.8 | 23.5 | 0.2 | 1.2 | 23.6 | 20.9 | 225 | 13 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| 1964 | 5 | 11 | 5.6 | 31.2 | 19 | 17 | 0.9 | 2.8 | 11.3 | 26.2 | 45 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| 1965 | 0 | 6.5 | 10.6 | 51.5 | 14.3 | 8.8 | 8.8 | 12.6 | 43.6 | 26.6 | 80 | 97.1 | 85.3 | 474.6 | 1.3 | 1 | 0 | 0 | 0 | 0 |
| 1966 | 2 | 4 | 24 | 41 | 25 | 26 | 7 | 4 | 3 | 1 | 11 | 14 | 16 | 93 | 118 | 26 | 0 | 0 | 0 | 0 |
| 1967 | 5 | 6 | 19 | 26 | 21 | 5 | 7 | 0 | 1 | 11 | 12 | 2 | 1 | 6 | 47 | 57 | 0 | 0 | 0 | 0 |
| 1968 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| 1969 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| 1970 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| 1971 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 3 | 0 |
| 1972 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 2 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| **Total** | **575** | **1143** | **6757** | **5997** | **3064.8** | **2815.7** | **2245** | **2561.7** | **6709.4** | **7677.4** | **8431.3** | **6023.6** | **2322.1** | **2973.4** | **2062.47** | **1195.2** | **1055.27** | **652.167** | **207.2** | **114.4** |

**Breeding Ground Data**

*Breeding Stock D*

*Absolute abundance estimate*

An estimate of absolute abundance of 28,830 individuals (95% CI[9] = 23,710-40,100) was computed from line transect aerial surveys conducted off Western Australia in 2008 and corrected for animals missed on the trackline (g(0) =0.41) (Hedley *et al.*, 2011).

*Relative abundance estimates*

**Table A. 3:** BSD Relative Abundance Index I (Hedley *et al.*, 2011). These are derived from three sets of aerial line transect surveys conducted in 1999, 2005 and 2008 (augmented with two shorter land-based surveys in 2005 and 2008) to estimate the population size of northward migrating whales.

| Year | Estimate | 95% CI |
|------|----------|--------------|
| 1999 | 5,130 | 3,380-8,750 |
| 2005 | 6,070 | 4,420-11,020 |
| 2008 | 11,820 | 9,720-16,400 |

**Table A. 4:** BSD Relative Abundance Index II (Bannister and Hedley, 2001). These are breeding ground relative abundance estimates from Bannister and Hedley (2001) for the period 1982 to 1994. No CV is available.

| Year | Estimate |
|------|----------|
| 1982 | 10.2 |
| 1986 | 16.2 |
| 1988 | 12.7 |
| 1991 | 23.6 |
| 1994 | 36.0 |

**Table A. 5:** BSD Relative Abundance Index III (Chittleborough, 1965). Catch per unit effort data are available from four catchers operating on the west coast of Australia from June 25 to August 26 each year (Chittleborough, 1965) (Area IV: 70˚E-130˚E). No CVs are available.

| Year | CPUE |
|------|-------|
| 1950 | 0.475 |
| 1951 | 0.424 |
| 1952 | 0.347 |
| 1953 | 0.353 |
| 1954 | 0.351 |
| 1955 | 0.244 |
| 1956 | 0.178 |
| 1957 | 0.146 |
| 1958 | 0.123 |
| 1959 | 0.090 |
| 1960 | 0.062 |
| 1961 | 0.055 |
| 1962 | 0.051 |

*Minimum number of haplotypes*

Minimum number of haplotypes for BSD from Olavarría *et al.* (2007) is 53.

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[9] This 95% CI was converted into a rough CV by assuming that the estimate was log-normally distributed. An approximation of the standard error of the log of the estimate was obtained by computing 0.5*(ln(40100)-ln(23710))/1.96. The resulting value of 0.13 was then taken to be the CV of the estimate (see footnote 6).

***Breeding Stock E1***

*Absolute abundance estimate*

i. BSE1 absolute abundance estimate I - Noad *et al.* (2011)
A land-based survey was conducted at Point Lookout on the east coast of Australia over 8 weeks in June and July 2010. The average number of whales passing per 10h over the peak four weeks of the northward migration was 84.7 ± 3.2 whales. A correction for whales available but missed was applied using double blind counts, as well as other corrections for sighting heterogeneity (1.212 +/- 0.049, Dunlop *et al.*, 2010). Using this correction the abundance estimate for 2010 was 14,522 whales (95% CI[10] 12,777 – 16,504) (Noad *et al.*, 2011).

ii. BSE1 absolute abundance estimate I I - Paton *et al.* (2011)
From a multi-point mark-recapture estimate of absolute abundance in 2005 for the east coast of Australia. Estimate is 7,041 (95% CI = 4,075-10,008) (Paton *et al.*, 2011).

*Relative abundance estimates*

**Table A. 6:** BSE1 Relative Abundance Index I (Noad *et al.*, 2011): A count of northward migrating whales from land-based surveys conducted at Point Lookout and two other locations. The values give the number of whales passing per 10h during four weeks of the peak migration. (M. Noad, *pers. commn*) and are as used for estimates of abundance provided by Noad *et al.*, (2008), Noad *et al.,* (2011). These data was used to in estimated annual rate of increase of 10.9%/year (95% CI = 10.5-11.3%/year) for a 24 year period (1984 to 2010) (Noad *et al.,* 2011).

| Year | Estimate |
|------|----------|
| 1984 | 6.12 |
| 1985 | 5.92 |
| 1986 | 8.25 |
| 1987 | 8.53 |
| 1988 | 9.15 |
| 1989 | 10.22 |
| 1990 | 11.58 |
| 1991 | 12.93 |
| 1992 | 14.36 |
| 1994 | 17.75 |
| 1996 | 20.91 |
| 1998 | 28.45 |
| 1999 | 27.45 |
| 2001 | 34.67 |
| 2002 | 37.34 |
| 2004 | 47.11 |
| 2007 | 70.73 |
| 2010 | 84.7 |

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[10] Similar to BSD, this 95% CI was converted into a rough CV by assuming that the estimate was log-normally distributed. An approximation of the standard error of the log of the estimate was obtained by computing 0.5*(ln(16504)-ln(12777))/1.96. The resulting value of 0.065 was then taken to be the CV of the estimate (see footnote 6).

**Table A. 7:** BSE1 Relative Abundance Index II (Chittleborough, 1965): Catch per unit effort data from two catcher boats operating on the east coast of Australia from June 10 to August 5 each year (Chittleborough, 1965) (Area V: 130˚E-170˚W). No CVs are available.

| Year | Estimate |
|------|----------|
| 1953 | 0.97 |
| 1954 | 0.76 |
| 1955 | 0.78 |
| 1956 | 0.7 |
| 1957 | 0.71 |
| 1958 | 0.75 |
| 1959 | 0.74 |
| 1960 | 0.52 |
| 1961 | 0.23 |
| 1962 | 0.69 |

*Mark-recapture data*

**Table A. 8:** BSE1 microsatellite genotypic mark-recapture data for males and females combined (Jackson *et al.,* 2012).

| Sexes combined | 1999 | 2000 | 2001 | 2002 | 2003 | 2004 |
|----------------|------|------|------|------|------|------|
| Total individual captures | 4 | 72 | 187 | 222 | 154 | 126 |
| 1999 | X | 0 | 0 | 0 | 0 | 0 |
| 2000 | | X | 8 | 6 | 1 | 0 |
| 2001 | | | X | 12 | 8 | 5 |
| 2002 | | | | X | 8 | 5 |
| 2003 | | | | | X | 5 |
| 2004 | | | | | | X |

**Table A. 9:** BSE1 microsatellite genotypic mark-recapture data for males only (Jackson *et al.,* 2012).

| Males | 1999 | 2000 | 2001 | 2002 | 2003 | 2004 |
|-------|------|------|------|------|------|------|
| Total individual captures | 2 | 38 | 96 | 128 | 84 | 80 |
| 1999 | X | 0 | 0 | 0 | 0 | 0 |
| 2000 | | X | 3 | 3 | 1 | 0 |
| 2001 | | | X | 6 | 4 | 3 |
| 2002 | | | | X | 3 | 4 |
| 2003 | | | | | X | 4 |
| 2004 | | | | | | X |

**Table A. 10:** BSE1 microsatellite genotypic mark-recapture data for females only (Jackson *et al.,* 2012).

| Females | 1999 | 2000 | 2001 | 2002 | 2003 | 2004 |
|---------|------|------|------|------|------|------|
| Total individual captures | 2 | 34 | 91 | 94 | 70 | 46 |
| 1999 | X | 0 | 0 | 0 | 0 | 0 |
| 2000 | | X | 5 | 3 | 0 | 0 |
| 2001 | | | X | 6 | 4 | 2 |
| 2002 | | | | X | 5 | 1 |
| 2003 | | | | | X | 1 |
| 2004 | | | | | | X |

**Table A. 11:** BSE1 photo-ID mark-recapture data from Forestell *et al.* (2011), provided by E. Martinez (*pers. commn*)

|   | 87 | 88 | 89 | 90 | 91 | 92 | 93 | 94 | 95 | 96 | 97 | 98 | 99 | 00 | 01 | 02 | 03 | 04 | 05 | 06 | 07 |
|---|----|----|----|----|----|----|----|----|----|----|----|----|----|----|----|----|----|----|----|----|----|
| n | 30 | 179 | 156 | 105 | 129 | 120 | 212 | 173 | 89 | 126 | 160 | 236 | 189 | 219 | 0 | 173 | 0 | 232 | 451 | 587 | 649 |
| 87 | X | 9 | 2 | 3 | 1 | 1 | 1 | 0 | 0 | 0 | 0 | 0 | 1 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 1 |
| 88 |   | X | 40 | 10 | 9 | 8 | 8 | 6 | 3 | 2 | 3 | 4 | 1 | 4 | 0 | 1 | 0 | 1 | 1 | 3 | 2 |
| 89 |   |   | X | 18 | 16 | 9 | 11 | 8 | 6 | 1 | 2 | 4 | 4 | 1 | 0 | 4 | 0 | 0 | 1 | 0 | 1 |
| 90 |   |   |   | X | 10 | 10 | 10 | 4 | 2 | 0 | 1 | 2 | 3 | 2 | 0 | 0 | 0 | 0 | 1 | 1 | 2 |
| 91 |   |   |   |   | X | 11 | 18 | 11 | 2 | 7 | 2 | 5 | 2 | 1 | 0 | 0 | 0 | 1 | 2 | 1 | 1 |
| 92 |   |   |   |   |   | X | 20 | 15 | 1 | 4 | 2 | 7 | 1 | 4 | 0 | 2 | 0 | 0 | 1 | 2 | 0 |
| 93 |   |   |   |   |   |   | X | 38 | 13 | 9 | 6 | 6 | 8 | 1 | 0 | 4 | 0 | 1 | 7 | 4 | 2 |
| 94 |   |   |   |   |   |   |   | X | 16 | 20 | 8 | 9 | 8 | 3 | 0 | 4 | 0 | 1 | 6 | 3 | 0 |
| 95 |   |   |   |   |   |   |   |   | X | 7 | 2 | 6 | 1 | 4 | 0 | 1 | 0 | 3 | 6 | 1 | 1 |
| 96 |   |   |   |   |   |   |   |   |   | X | 17 | 11 | 5 | 6 | 0 | 2 | 0 | 1 | 5 | 4 | 0 |
| 97 |   |   |   |   |   |   |   |   |   |   | X | 25 | 5 | 7 | 0 | 8 | 0 | 1 | 2 | 5 | 0 |
| 98 |   |   |   |   |   |   |   |   |   |   |   | X | 21 | 13 | 0 | 10 | 0 | 2 | 8 | 7 | 5 |
| 99 |   |   |   |   |   |   |   |   |   |   |   |   | X | 18 | 0 | 4 | 0 | 2 | 8 | 5 | 9 |
| 00 |   |   |   |   |   |   |   |   |   |   |   |   |   | X | 0 | 11 | 0 | 5 | 15 | 11 | 3 |
| 01 |   |   |   |   |   |   |   |   |   |   |   |   |   |   | X | 0 | 0 | 0 | 0 | 0 | 0 |
| 02 |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   | X | 0 | 9 | 17 | 12 | 9 |
| 03 |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   | X | 0 | 0 | 0 | 0 |
| 04 |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   | X | 17 | 16 | 11 |
| 05 |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   | X | 45 | 22 |
| 06 |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   | X | 57 |
| 07 |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   | X |

*Minimum number of haplotypes*

The minimum number of haplotypes for BSE1 is 42, with 5 of them being private to the South Pacific (Olavarría *et al.*, 2006).

*Oceania breeding stock*

*Absolute abundance estimate*

The estimate in 2005 of 4,329 individuals (CV=0.12) arises from a sighting-resighting analysis of microsatellite genotypes collected from 1999 to 2005 across four survey areas in Oceania: New Caledonia (E2), Tonga (E3), the Cook Islands and French Polynesia (F2) (Constantine *et al.*, 2012). It is a doubled male-specific estimate assuming equal numbers of females in the region.

*Mark recapture data*

**Table A. 12:** Synoptic genotypic mark recapture data underlying male specific Oceania-wide abundance estimate. This is the males-only subset of the sexes combined dataset from Constantine *et al.* (2012), provided by Jackson (*pers. commn,* 2012).

| Year initial capture (males) | 1999 | 2000 | 2001 | 2002 | 2003 | 2004 | 2005 |
|---|---|---|---|---|---|---|---|
| Total individuals captured | 25 | 70 | 112 | 78 | 114 | 24 | 82 |
| 1999 | - | 3 | 4 | 0 | 3 | 0 | 1 |
| 2000 | | - | 5 | 3 | 8 | 2 | 6 |
| 2001 | | | - | 7 | 12 | 3 | 7 |
| 2002 | | | | - | 4 | 0 | 6 |
| 2003 | | | | | - | 1 | 11 |
| 2004 | | | | | | - | 3 |
| 2005 | | | | | | | - |

**Table A. 13:** Oceania microsatellite genotypic mark-recapture data for males and females combined (Jackson *et al.,* 2012).

| Sexes combined | 1999 | 2000 | 2001 | 2002 | 2003 | 2004 |
|---|---|---|---|---|---|---|
| Total individual captures | 52 | 114 | 183 | 130 | 216 | 79 |
| 1999 | X | 3 | 5 | 3 | 2 | 1 |
| 2000 | | X | 6 | 5 | 9 | 2 |
| 2001 | | | X | 9 | 18 | 6 |
| 2002 | | | | X | 7 | 2 |
| 2003 | | | | | X | 2 |
| 2004 | | | | | | X |

**Table A. 14:** Oceania microsatellite genotypic mark-recapture data for males only (Jackson *et al.,* 2012).

| Males | 1999 | 2000 | 2001 | 2002 | 2003 | 2004 |
|---|---|---|---|---|---|---|
| Total individual captures | 27 | 72 | 120 | 84 | 131 | 41 |
| 1999 | X | 3 | 2 | 0 | 1 | 0 |
| 2000 | | X | 5 | 3 | 6 | 1 |
| 2001 | | | X | 7 | 10 | 3 |
| 2002 | | | | X | 4 | 0 |
| 2003 | | | | | X | 1 |
| 2004 | | | | | | X |

**Table A. 15:** Oceania microsatellite genotypic mark-recapture data for females only (Jackson *et al.,* 2012).

| Females | 1999 | 2000 | 2001 | 2002 | 2003 | 2004 |
|---|---|---|---|---|---|---|
| Total individual captures | 25 | 42 | 63 | 46 | 85 | 38 |
| 1999 | X | 0 | 3 | 3 | 1 | 1 |
| 2000 | | X | 1 | 2 | 3 | 1 |
| 2001 | | | X | 2 | 8 | 3 |
| 2002 | | | | X | 3 | 2 |
| 2003 | | | | | X | 1 |
| 2004 | | | | | | X |

*Minimum number of haplotypes*

The minimum number of haplotypes for Oceania is 115 (Olavarría *et al.*, 2007).

**Feeding Ground Data**

*Breeding Stock D*

**Table A. 16:** BSD Relative Abundance Index IV (Branch, 2011). Feeding ground estimates of abundance from IDCR-SOWER CPI-CPIII surveys (south of 60°S) associated with breeding stock D correspond to sector 60°E-120°E of the Southern Oceans (Branch, 2011). Current nuclear area for feeding ground catch allocation for BSD corresponds to longitudinal sector 80°E-110°E and margin area corresponds to 60°E-130°E (IWC, 2010).

| Year | Estimate | CV | Estimates for comparable areas | CV |
|------|----------|------|-------------------------------|------|
| 1978 | 1,033 | 0.44 | 1,219 | 0.46 |
| 1988 | 3,869 | 0.52 | 4,202 | 0.52 |
| 1997 | 17,959 | 0.17 | 17,959 | 0.17 |

**Table A. 17:** BSD Relative Abundance Index V (Matsuoka *et al.*, 2011): JARPA surveys conducted during 1989/90-2004/05 austral summer seasons (January and February) alternating survey areas between Area IV (70°E-130°E) and Area V (130°E-170°W), all south of 60°S. Areas IV and V were divided into 2 sectors, western and eastern. Each sector was divided into northern (60°S to 45 nm from ice-edge) and southern (from ice-edge to 45 nm away). Breeding Stock D corresponds to Area IV (Matsuoka *et al.,* in press).

| Year | Estimate | CV |
|------|----------|-------|
| 1989 | 5325 | 0.302 |
| 1991 | 5408 | 0.188 |
| 1993 | 2747 | 0.153 |
| 1995 | 8066 | 0.142 |
| 1997 | 10657 | 0.166 |
| 1999 | 16751 | 0.143 |
| 2001 | 31134 | 0.123 |
| 2003 | 27783 | 0.115 |

*Breeding Stock E1*

**Table A. 18:** BSE1 Relative Abundance Index III (Branch, 2011). Feeding ground estimates of abundance from IDCR-SOWER CPI-CPIII surveys (south of 60°S) associated with Area V (130°E-170°W).

| Year | Estimate | CV | Estimates for comparable areas | CV |
|------|----------|------|-------------------------------|------|
| 1980 | 995 | 0.58 | 1,913 | 0.60 |
| 1985 | 622 | 050 | 622 | 0.50 |
| 1992 | 2,012 | 0.43 | 3,484 | 0.33 |
| 2001 | 13,300 | 0.22 | 13,300 | 0.20 |

**Table A. 19:** BSE1 Relative Abundance Index IV (Matsuoka *et al.*, 2011): JARPA surveys conducted during 1989/90-2004/05 austral summer seasons (January and February) alternating survey areas between Area IV (70°E-130°E) and Area V (130°E-170°W), all south of 60°S. Areas IV and V were divided into 2 sectors, western and eastern. Each sector was divided into northern (60°S to 45 nm from ice-edge) and southern (from ice-edge to 45 nm away). Breeding Stock E1 corresponds to Area V (Matsuoka *et al.,* 2011).

| Year | Estimate | CV |
|------|----------|-------|
| 1989 | 5325 | 0.302 |
| 1991 | 5408 | 0.188 |
| 1993 | 2747 | 0.153 |
| 1995 | 8066 | 0.142 |
| 1997 | 10657 | 0.166 |
| 1999 | 16751 | 0.143 |
| 2001 | 31134 | 0.123 |
| 2003 | 27783 | 0.115 |

*Oceania breeding stock*

**Table A. 20:** Feeding ground estimates of abundance from IDCR-SOWER for breeding stock F correspond to sector 170°W-110°W (Branch 2011). Current nuclear area associated with Breeding Stocks E2, E3 and F is 180°-120°W and margin is 160°E-100°W (IWC, 2010).

| Year | Estimate | CV | Estimates for comparable areas | CV |
|------|----------|------|------|------|
| 1980 | 995 | 0.58 | 1,913 | 0.60 |
| 1985 | 622 | 050 | 622 | 0.50 |
| 1992 | 2,012 | 0.43 | 3,484 | 0.33 |
| 2001 | 13,300 | 0.22 | 13,300 | 0.20 |

**Data informing interchange**

*D and E1*

**Table A. 21:** Inter-regional recaptures between West and East Australia (Anderson and Brasseur, 2007). The first row gives the total number of East Australia animals that were sighted in 2002 and 2003, while the second row gives the total number of West Australia animals that were sighted in 2002 and 2003. Entries above the diagonal of X's would reflect animals that were first seen in West Australia and then later re-seen in East Australia. Entries below the diagonal would reflect animals first seen in East Australia and later resighted in West Australia

|  | EA 2002 | EA 2003 |
|------|------|------|
| Total East Australia | 216 | 131 |
| Total West Australia | 89 | 144 |
| WA 2002 | X | 0 |
| WA 2003 | 0 | X |

*E1 and Oceania*

**Table A. 22:** Inter-regional recaptures between East Australia and Oceania, from microsatellite genotypic mark-recapture data for males and females combined (Jackson *et al.,* 2012). Note that entries above the diagonal of the matrix reflect animals that were first seen in Oceania, and later re-sighted in EA, while entries below the diagonal reflect animals that were first seen in EA and later re-sighted in Oceania.

| Sexes combined | 1999 | 2000 | 2001 | 2002 | 2003 | 2004 |
|------|------|------|------|------|------|------|
| Total East Australia | 4 | 72 | 187 | 222 | 154 | 126 |
| Total Oceania | 52 | 114 | 183 | 130 | 216 | 79 |
| 1999 | X | 1 | 0 | 1 | 0 | 0 |
| 2000 | 0 | X | 0 | 0 | 0 | 0 |
| 2001 | 0 | 0 | X | 2 | 0 | 2 |
| 2002 | 0 | 0 | 0 | X | 0 | 0 |
| 2003 | 0 | 1 | 0 | 1 | X | 0 |
| 2004 | 0 | 0 | 0 | 0 | 0 | X |

**Table A. 23:** Inter-regional recaptures between East Australia and Oceania, from microsatellite genotypic mark-recapture data for males and females combined (Jackson *et al.,* 2012).

| Males | 1999 | 2000 | 2001 | 2002 | 2003 | 2004 |
|------|------|------|------|------|------|------|
| Total East Australia | 2 | 38 | 96 | 128 | 84 | 80 |
| Total Oceania | 27 | 72 | 120 | 84 | 131 | 41 |
| 1999 | X | 1 | 0 | 1 | 0 | 0 |
| 2000 | 0 | X | 0 | 0 | 0 | 0 |
| 2001 | 0 | 0 | X | 1 | 0 | 2 |
| 2002 | 0 | 0 | 0 | X | 0 | 0 |
| 2003 | 0 | 1 | 0 | 1 | X | 0 |
| 2004 | 0 | 0 | 0 | 0 | 0 | X |

**Table A. 24:** Inter-regional recaptures between East Australia and Oceania, from microsatellite genotypic mark-recapture data for males and females combined (Jackson *et al.,* 2012).

| Females | 1999 | 2000 | 2001 | 2002 | 2003 | 2004 |
|---|---|---|---|---|---|---|
| Total East Australia | 4 | 72 | 187 | 222 | 154 | 126 |
| Total Oceania | 52 | 114 | 183 | 130 | 216 | 79 |
| 1999 | X | 1 | 0 | 1 | 0 | 0 |
| 2000 | 0 | X | 0 | 0 | 0 | 0 |
| 2001 | 0 | 0 | X | 2 | 0 | 2 |
| 2002 | 0 | 0 | 0 | X | 0 | 0 |
| 2003 | 0 | 1 | 0 | 1 | X | 0 |
| 2004 | 0 | 0 | 0 | 0 | 0 | X |

**APPENDIX B – MODEL DIAGRAM FOR THE BSD SINGLE-STOCK MODEL**
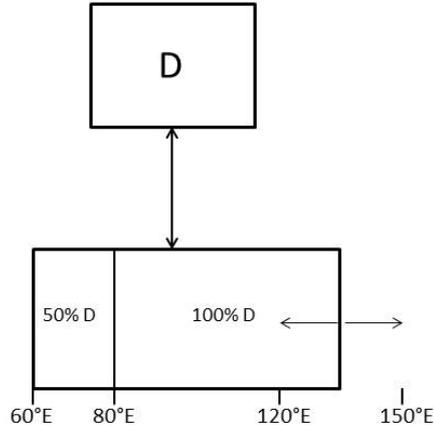


**Single stock BSD model:** This model aims to explore the effect of moving the Antarctic catch boundaries. Note that the Hedley *et al.* (2011) absolute abundance estimate is not used in the model fitting process. An uninformative uniform prior of $U[\ln 15000, \ln 40000]$ is utilised for the log of the target abundance estimate in the Bayesian estimation process.

**APPENDIX C – MODEL DIAGRAMS AND CATCH ALLOCATIONS FOR TWO-STOCK E1 VS O MODELS**
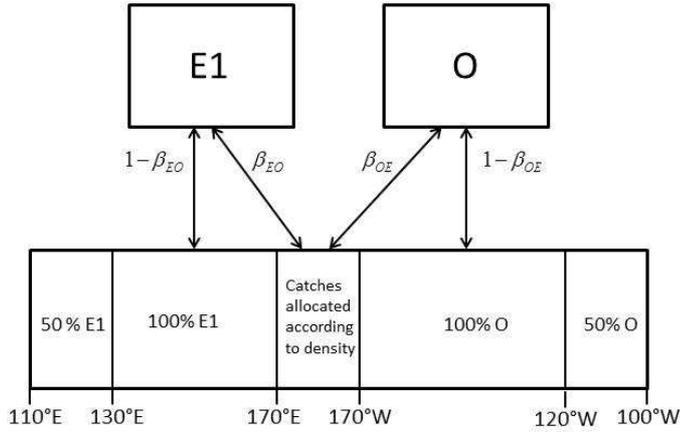


**E1_O#1:** Model diagram for a two-stock E1+O model. Antarctic catch boundaries remain fixed. It is assumed that a (time-invariant) proportion of each stock feeds in a common feeding ground between 170°E and 170°W, and catches in this area of overlap are allocated according to the number of whales present. Feeding ground catches are therefore allocated as follows:

$$C_y^{F,E1} = \frac{\beta_{EO}N_y^{E1}}{\beta_{EO}N_y^{E1} + \beta_{OE}N_y^{O}} C_y^{170E-170W} + C_y^{130E-170E} + 0.5 * C_y^{110E-130E}$$

$$C_y^{F,O} = \frac{\beta_{OE}N_y^{O}}{\beta_{EO}N_y^{E1} + \beta_{OE}N_y^{O}} C_y^{170E-170W} + C_y^{170W-120W} + 0.5 * C_y^{120W-100W}$$

Where

$\beta_{EO}$      is the proportion of BSE1 whales that feed between 170°E and 170°W each year, and

$\beta_{OE}$      is the proportion of BSO whales that feed between 170°E and 170°W each year.

Results for Run E1_O#1 are given in Table 3 and Figure 5.
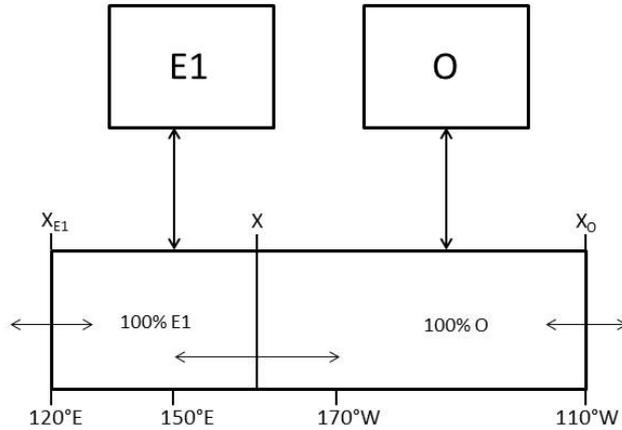


**E1_O#2.** Model diagram for a second two-stock model that aims to explore the effect of moving the boundaries for the Antarctic catches. The boundary marked by 'X' moves between 150°E and 170°W for various model iterations, and the boundaries marked $X_{E1}$ and $X_O$ move 10° in either direction from the current position. There is no overlap between the two stocks in the run, i.e. these are essentially two single-stock models run for a range of Antarctic catch boundaries. Results for Run E1_O#2 are given in Table 5 and Figure 6.

*Priors for the mixing proportion parameters*

$\beta_{EO}$ and $\beta_{OE}$ are drawn from uniform priors on the interval [0,1]. A constraint needs to be placed on the values of $\beta_{EO}$ and $\beta_{OE}$, as the uniform priors do not prevent a situation where nearly all of the BSD stock feeds in the E1 feeding area, and nearly all of the BSE1 stock feeds in the D feeding area, which is biologically implausible. The approach of Johnston and Butterworth (2005) was taken whereby the constraint is added that the proportion of BSE1 whales going to the E1 feeding area must be greater than the proportion of BSD whales, and *vice versa*. Mathematically this amounts to the constraint that $\beta_{EO} + \beta_{OE} < 1$.

# Assessment results for humpback breeding stocks D, E1 and Oceania following recommendations from SC 65a - ADDENDUM

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## INTRODUCTION

This addendum to document SC/65b/S04 contains the results for one further two-stock BES1-BSO model (a sensitivity run where there is no Antarctic catch boundary between the two stocks, and catches are allocated according to total population densities); two BSD-BSE1 two-stock models; and a third two-stock BSD-BSE1+BSE2 model where E1 (East Australia) and E2 (New Caledonia) are considered as one stock. In all cases involving BSD, the 2008 Hedley *et al* (2011) absolute abundance estimate was not included in the model fit, and an uninformative uniform prior of U[ln15000, ln40000] was used for the target abundance estimate for BSD. Finally results are given for a three-stock model similar to the one that was run for SC65a, except also excluding the Hedley *et al* (2011) absolute abundance estimate from the model fit, and instead using an uninformative uniform prior of U[ln15000,ln40000] for the BSD target abundance estimate.

The model diagrams are given in Appendix C-E. Appendix F describes the method used here to combine the BSE1+BSE2 data.

## RESULTS

Results for the third two-stock BSE1-BSO model (see E1_O#3 diagram in Appendix C) are given in Table App. 1 and Figure 4. Excluding the BSO $N_{min}$ constraints for this model makes quite a substantial difference, presumably since the fact that all catches between 130°E and 120°W are allocated based on the total population size allows for greater flexibility. Removing the $N_{min}$ constraint improves the BSO fit to the Constantine *et al.* (2012) mark-recapture data slightly.

Figure App. 2 shows the population trajectories and model fits for the base case BSD-BSE1 model (see D_E1#1 diagram in Appendix D). The corresponding posterior median values are given in Table App. 2 in row (a). Once again the removal of the 2008 Heldey *et al.* (2011) absolute abundance estimate from the data fitted has substantially improved the fit to the relative abundance series for BSD. The model depicted in diagram D_E1#2 in Appendix D explores the effect of moving the area of overlap between D and E1 eastward. The posterior median values for these are given in row (b) and (c) in Table App. 2, and the corresponding plots can be found in Figure App. 3a and Figure App. 3b. Results for the model that treats E1+E2 as a single stock (see D_E1#3 diagram in Appendix D) are given in row (d) of Table App. 2, and plotted in Figure App. 3c-d.

Posterior median values for the three-stock model are given in Table App. 3, and the population trajectories are plotted in Figure App. 4. The model has been run for both the case where the BSO $N_{min}$ constraint has been included and been excluded.

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**Table App. 1:** Posterior median values of key model parameters are given with their 90% probability intervals for the **third two-stock BSE1+BSO** model run (see the E1_O#3 diagram in Appendix C). For this model there is no Antarctic catch boundary between the two stocks, and Antarctic catches are allocated according to total population sizes. Results are shown for both the case where the $N_{min}$ constraint for BSO has been included and been excluded in the model fit.

| | $r$ | | $K$ | | $N_{min}$ | | $N_{2012}/K$ | | $N_{2040}/K$ | |
|---|---|---|---|---|---|---|---|---|---|---|
| BSE1 | 0.105 | [0.102,0.106] | 18869 | [17557,19742] | 253 | [213,297] | 0.796 | [0.743,0.843] | 1 | [1.000,1.000] |
| BSE1 (no $N_{min}$) | 0.105 | [0.103,0.106] | 26929 | [22647,28727] | 231 | [203,269] | 0.618 | [0.551,0.716] | 1 | [0.999,1.000] |
| BSO | 0.049 | [0.041,0.054] | 22414 | [21427,24632] | 496 | [463,660] | 0.175 | [0.149,0.211] | 0.596 | [0.439,0.720] |
| BSO (no $N_{min}$) | 0.094 | [0.071,0.105] | 11797 | [9807,17037] | 120 | [85,251] | 0.44 | [0.263,0.550] | 0.997 | [0.928,0.999] |

**Table App. 2:** Posterior median values of key model parameters are given with their 90% probability intervals for the **two-stock BSD-BSE1** model runs (see Appendix D). Base case (a) corresponds to model diagram D_E1#1, case (b) and (c) correspond to model diagrams D_E1#2, and case (d) corresponds to model diagram D_E1#3 in Appendix D. In all cases the model is fit to the Hedley *et al.* (2011) and Bannister and Hedley (2001) relative abundance series for BSD and the Noad *et al.* (2011) relative and absolute abundance estimates for BSE1. An uninformative uniform prior of U[ln15000,ln40000] has been used for the BSD target abundance estimate.

| BSD | $r$ | | $K$ | | $b_{DE}$ | | $N_{min}$ | | $N_{2012}/K$ | | $N_{2040}/K$ | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| (a) Base case | 0.085 | [0.041,0.104] | 21605 | [19014,32913] | 0.292 | [0.036,0.586] | 989 | [486,6423] | 0.9 | [0.700,0.986] | 1.000 | [0.972,1.000] |
| (b) 120E-140E | 0.087 | [0.044,0.104] | 22824 | [20477,35042] | 0.238 | [0.030,0.581] | 930 | [444,7232] | 0.887 | [0.615,0.983] | 1.000 | [0.958,1.000] |
| (c) 130E-150E | 0.088 | [0.044,0.104] | 23637 | [21415,70000] | 0.136 | [0.009,0.428] | 831 | [402,55095] | 0.862 | [0.291,0.976] | 1.000 | [0.334,1.000] |
| (d) E1+E2 | 0.085 | [0.041,0.104] | 21714 | [19037,33214] | 0.301 | [0.044,0.650] | 1073 | [449,6652] | 0.902 | [0.685,0.988] | 1.000 | [0.977,1.000] |
| BSE1 | $r$ | | $K$ | | $b_{ED}$ | | $N_{min}$ | | $N_{2012}/K$ | | $N_{2040}/K$ | |
| (a) Base case | 0.105 | [0.103,0.106] | 25820 | [24511,27044] | 0.196 | [0.036,0.335] | 229 | [202,259] | 0.633 | [0.574,0.693] | 1.000 | [0.999,1.000] |
| (b) 120E-140E | 0.105 | [0.103,0.106] | 24147 | [22889,25269] | 0.204 | [0.040,0.339] | 225 | [199,264] | 0.663 | [0.592,0.729] | 1.000 | [1.000,1.000] |
| (c) 130E-150E | 0.105 | [0.028,0.106] | 23346 | [21275,70000] | 0.548 | [0.217,0.917] | 223 | [198,60266] | 0.677 | [0.225,0.750] | 1.000 | [0.332,1.000] |
| (d) E1+E2 | 0.105 | [0.103,0.106] | 32716 | [31368,33974] | 0.141 | [0.020,0.263] | 254 | [226,289] | 0.565 | [0.516,0.622] | 0.999 | [0.999,1.000] |

**Table App. 3:** Posterior median values of key model parameters are given with their 90% probability intervals for the **three-stock** model run (see Appendix E). The model has been run for both the case where the BSO $N_{min}$ constrain has been included and excluded. In both cases, the model is fit to the Hedley *et al.* (2011) and Bannister and Hedley (2001) relative abundance series for BSD, the Noad *et al.* (2011) relative and absolute abundance estimates for BSE1 and to the Constantine *et al.* (2012) mark-recapture data for BSO. An uninformative uniform prior of U[ln15000,ln40000] has been used for the BSD target abundance estimate.

| BSD | $r$ | | $K$ | | $N_{min}$ | | $N_{2012}/K$ | | $N_{2040}/K$ | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| $N_{min}$ included | 0.072 | [0.025,0.101] | 23441 | [19415,59865] | 1826 | [452,26924] | 0.889 | [0.492,0.998] | 0.999 | [0.652,1.000] | | |
| $N_{min}$ excluded | 0.090 | [0.033,0.099] | 20552 | [18920,36808] | 1106 | [579,11631] | 0.934 | [0.652,0.995] | 1.000 | [0.929,1.000] | | |
| BSE1 | $r$ | | $K$ | | $N_{min}$ | | $N_{2012}/K$ | | $N_{2040}/K$ | | | |
| $N_{min}$ included | 0.105 | [0.102,0.106] | 26809 | [21332,30695] | 235 | [201,303] | 0.615 | [0.497,0.724] | 1.000 | [0.999,1.000] | | |
| $N_{min}$ excluded | 0.105 | [0.102,0.106] | 26809 | [23344,30655] | 235 | [198,285] | 0.625 | [0.476,0.700] | 1.000 | [0.999,1.000] | | |
| BSO | $r$ | | $K$ | | $N_{min}$ | | $N_{2012}/K$ | | $N_{2040}/K$ | | | |
| $N_{min}$ included | 0.033 | [0.007,0.060] | 18121 | [13925,26693] | 1055 | [382,2499] | 0.209 | [0.118,0.299] | 0.443 | [0.138,0.895] | | |
| $N_{min}$ excluded | 0.080 | [0.015,0.101] | 16033 | [11129,23143] | 192 | [92,1644] | 0.326 | [0.144,0.481] | 0.982 | [0.224,0.998] | | |
| Interchange | $\beta_{DE}$ | | $\beta_{ED}$ | | $\gamma$ | | $\gamma^*$ | | $\beta_{EO}$ | | $\beta_{OE}$ | |
| $N_{min}$ included | 0.271 | [0.040,0.807] | 0.060 | [0.012,0.296] | 0.071 | [0.013,0.234] | 0.676 | [0.545,0.781] | 0.137 | [0.008,0.297] | 0.072 | [0.004,0.260] |
| $N_{min}$ excluded | 0.412 | [0.047,0.666] | 0.104 | [0.012,0.209] | 0.065 | [0.009,0.167] | 0.577 | [0.368,0.771] | 0.280 | [0.024,0.462] | 0.117 | [0.012,0.398] |

**(a) BSE1 (E1_O#3)**



**(b) BSO (E1_O#3)**



**(c) BSO - Constantine et al. (2012)**
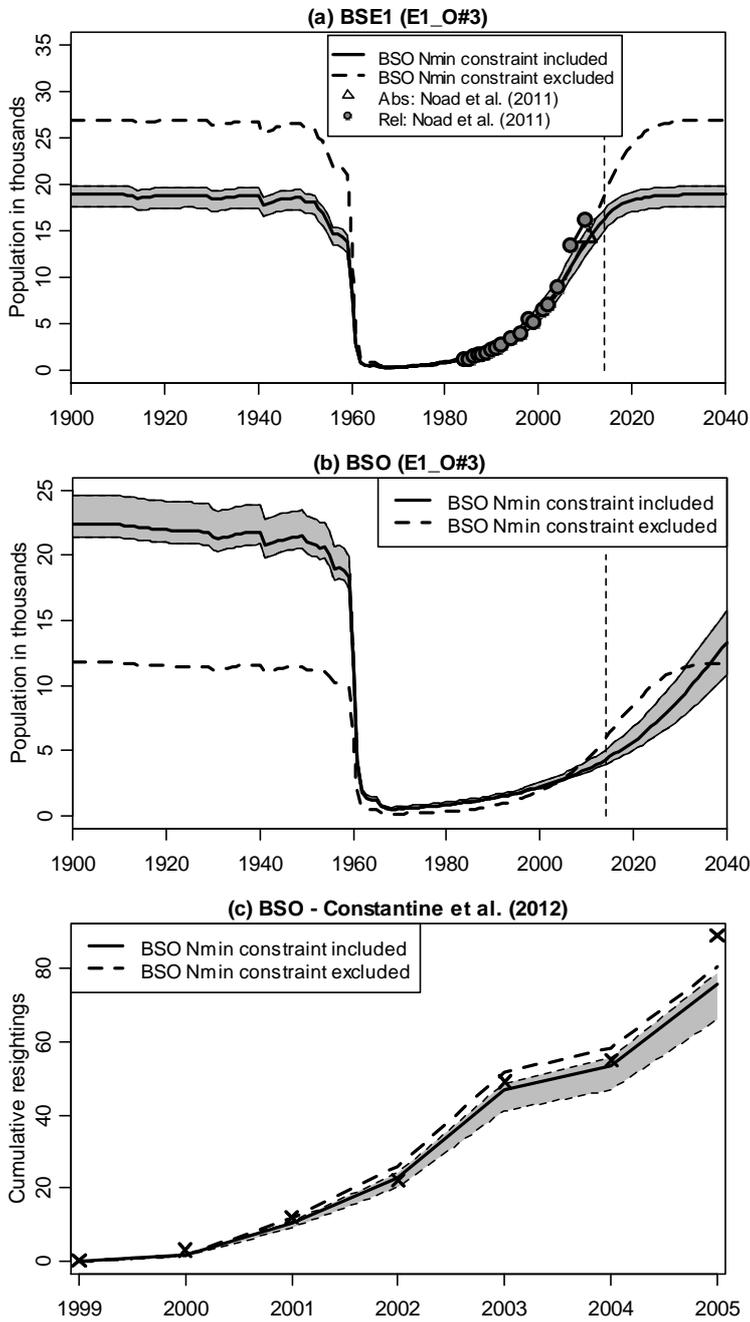


**Figure App. 1:** Figure 4a and b show the posterior median population trajectories and 90% probability envelopes for the **third two-stock BSE1+BSO** model (see the E1_O#3 diagram in Appendix C). In all the figures, the solid line indicates the trajectory for the case when the $N_{min}$ constraint for BSO has been included, while the dashed line shows the case where it has been excluded. The model is fit to the Noad *et al.* (2011) absolute and relative abundance series for BSE1 (fits shown in Figure 4a), and to the Constantine *et al.* (2012) mark-recapture data for BSO (Figure 4c). In Figure 4c, the cumulative observed re-sightings are marked by X's. The median estimates are shown by the thick line and their 90% probability envelope is indicated by the shaded region.
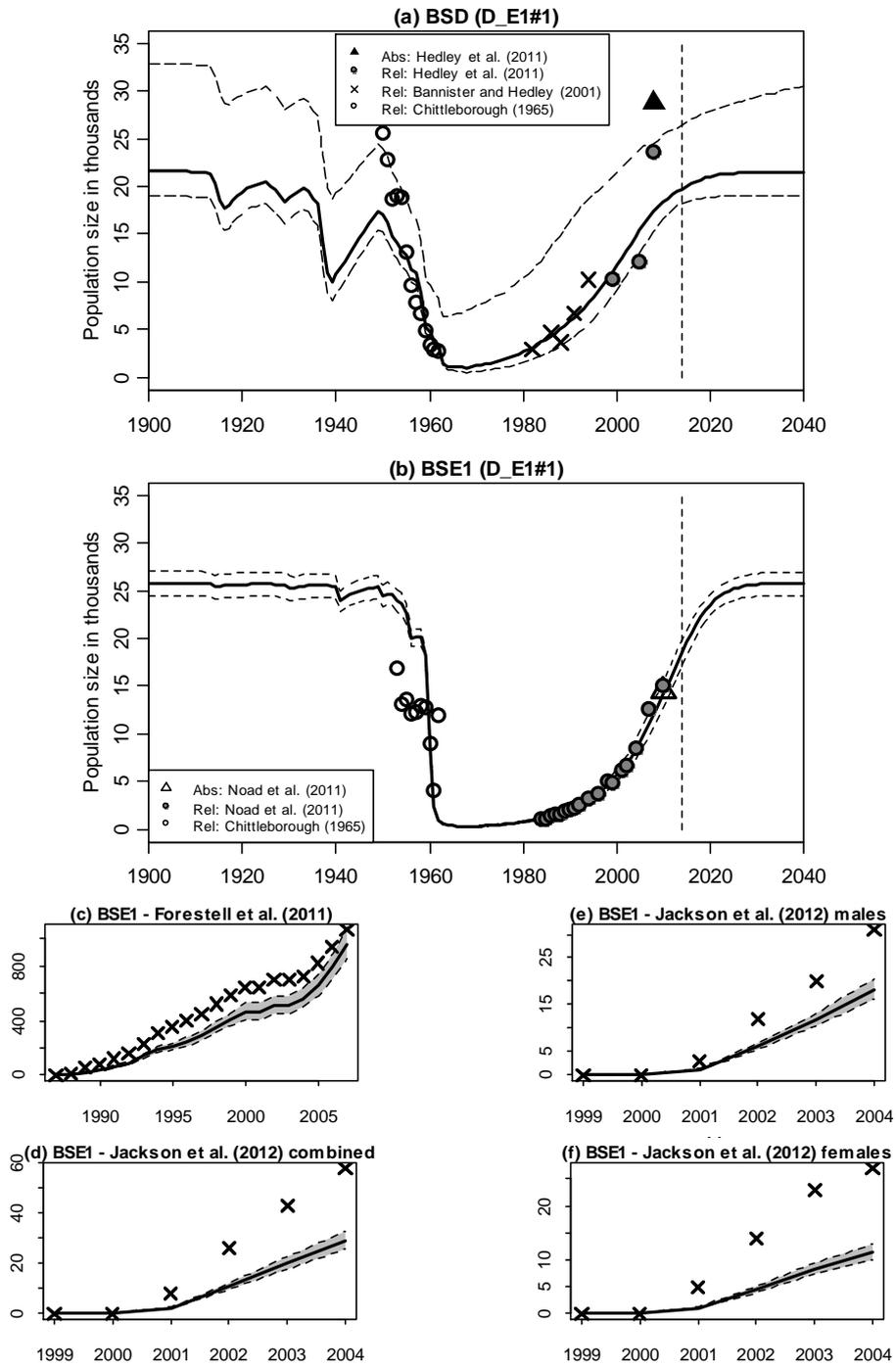
**Figure App. 2:** Posterior median population trajectories and 90% probability envelopes for the **first two-stock BSD+BSE1** model (see the D_E1 #1 diagram in Appendix D). The model has been fit to the Hedley *et al.* (2011) and Bannister and Hedley (2001) relative abundance series for BSD, and to the Noad *et al.* (2011) relative and absolute abundance estimates for BSE1. Fits to the BSE1 mark-recapture data have been shown as consistency checks.
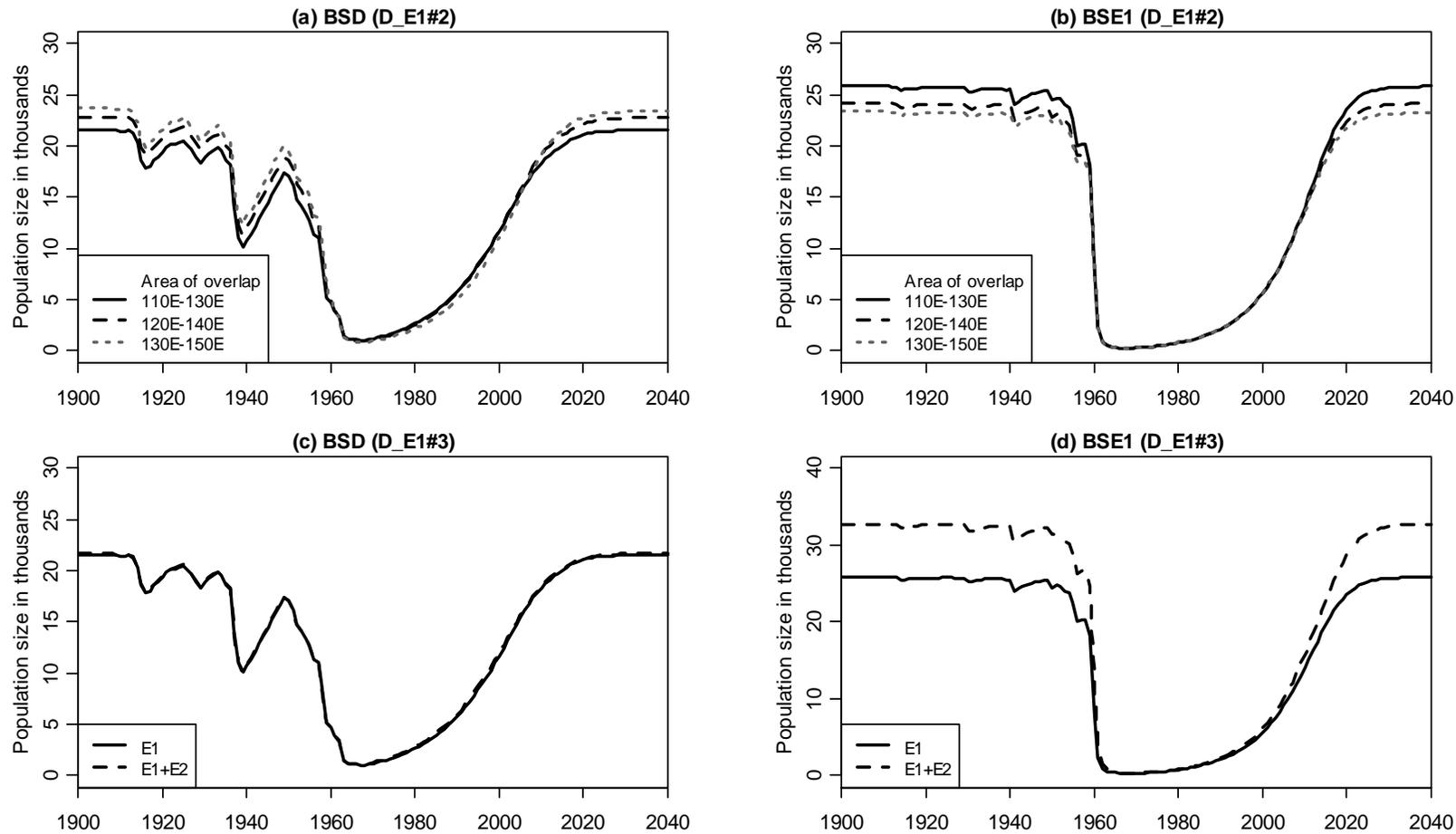
**Figure App. 3:** Figure App. 3a and Figure App. 3b show the posterior median population trajectories for the **second two-stock BSD+BSE1** model (see the D_E1 #2 diagram in Appendix D), where the region of overlap in the Antarctic between the two stocks is shifted eastward. Figure App**. 3**c and Figure App**. 3**d show the posterior median population trajectories for the **third two-stock BSD+BSE1** model (see the D_E1 #2 diagram in Appendix D), where BSE1 and BSE2 (East Australia and New Caledonia) are treated as a single stock. The solid black line in all the figures is the base case BSD+BSE1 model, also shown in Figure App. 2.

**(a) BSD (three-stock)**

Abs: Hedley et al. (2011)
Rel: Hedley et al. (2011)
Rel: Bannister and Hedley (2001)
Rel: Chittleborough (1965)

**(b) BSE1 (three-stock)**

Abs: Noad et al. (2011)
Rel: Noad et al. (2011)
Rel: Chittleborough (1965)

**(c) BSO (three-stock)**

Median population trajectory
$N_{min}$ excluded
Constantine et al. (2001) abs est
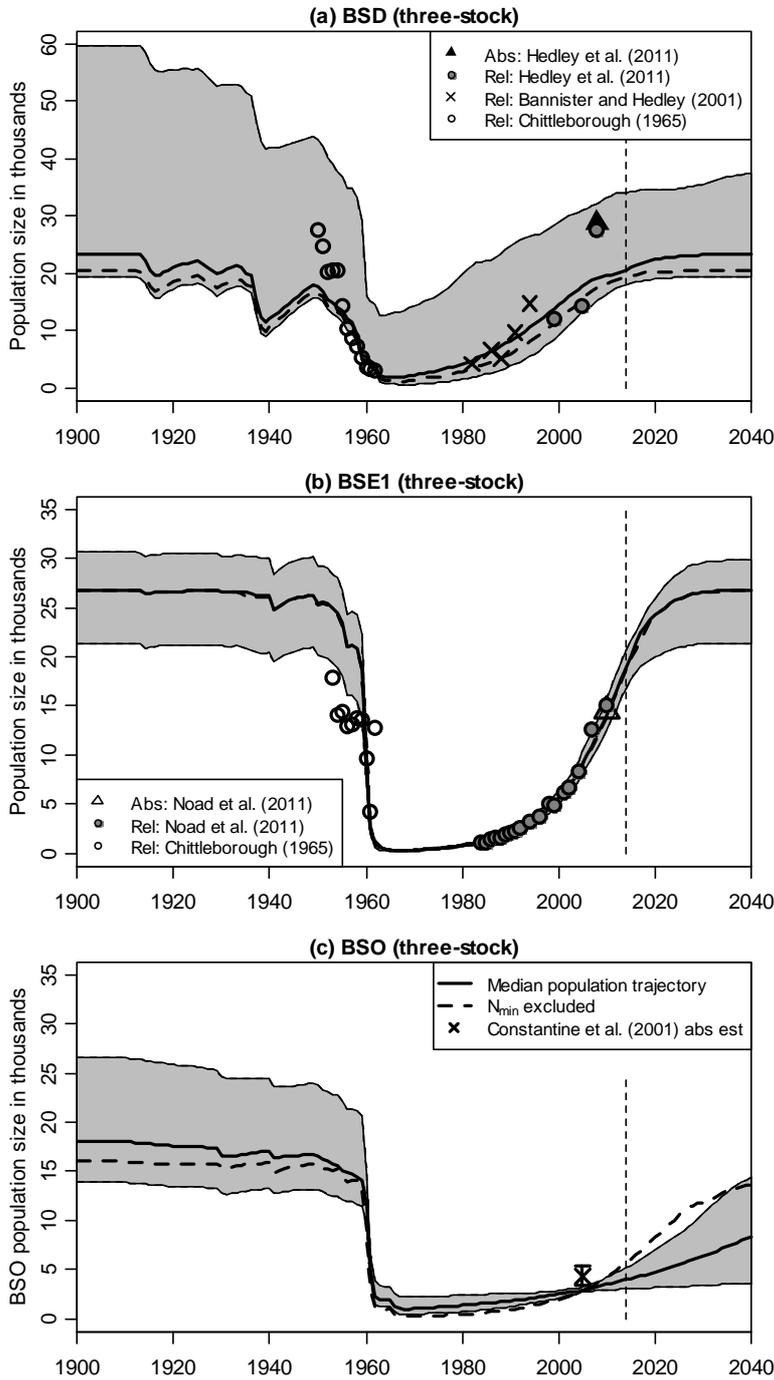
**Figure App. 4**: Posterior median population trajectories and 90% probability envelopes for the **three-stock BSD+BSE1+BSO** model (see the diagram in Appendix E). In the above figures, the solid line indicates the trajectory when the $N_{min}$ constraint for BSO has been included, while the dashed line shows the case where it has been excluded. The model is fit to the Hedley *et al.* (2011) and Bannister and Hedley (2001) relative abundance series for BSD, the Noad *et al.* (2011) relative and absolute abundance estimates for BSE1 and to the Constantine *et al.* (2012) mark-recapture data for BSO. An uninformative uniform prior of U[ln15000,ln40000] has been used for the BSD target abundance estimate.

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**APPENDIX C (CONTINUED) – A FURTHER TWO-STOCK BSE1-BSO MODEL**
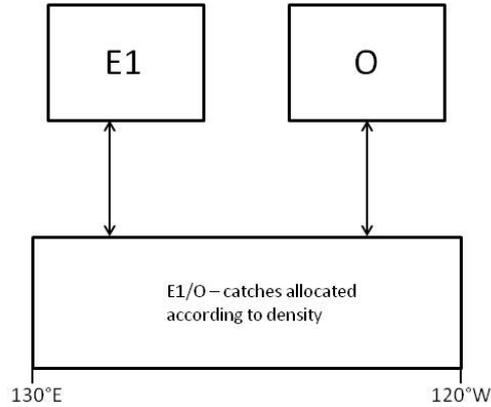


**E1_O#3:** Model diagram for a two-stock E1+O model. There is no Antarctic catch boundary between BSE1 and BSO, and feeding ground catches are allocated in proportion to total population sizes as follows:

$$C_y^{F,E1} = \frac{N_y^{E1}}{N_y^{E1} + N_y^{O}} C_y^{130E-120W} \tag{C.1}$$

$$C_y^{F,O} = \frac{N_y^{O}}{N_y^{E1} + N_y^{O}} C_y^{130E-120W} \tag{C.2}$$

**APPENDIX D – MODEL DIAGRAMS AND CATCH ALLOCATIONS FOR TWO-STOCK BSD+E1 MODELS**
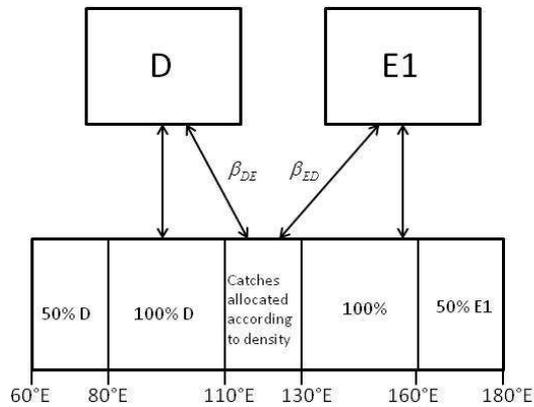


**D_E1#1:** Model diagram for a two-stock BSD (West Australia) – BSE1 (East Australia) model. It is assumed that a (time-invariant) proportion of each stock feeds in a common feeding ground between 110°E and 130°E, and catches in this area of overlap are allocated according to the number of whales present. Feeding ground catches are therefore allocated as follows:

$$C_y^{F,D} = 0.5 * C_y^{60E-80E} + C_y^{80E-110E} + \frac{\beta_{DE} N_y^{D}}{\beta_{ED} N_y^{E1} + \beta_{DE} N_y^{D}} C_y^{110E-130E} \tag{D.1}$$

$$C_y^{F,E1} = \frac{\beta_{ED} N_y^{E1}}{\beta_{ED} N_y^{E1} + \beta_{DE} N_y^{D}} C_y^{110E-130E} + C_y^{130E-160E} + 0.5 * C_y^{160E-180E} \tag{D.2}$$
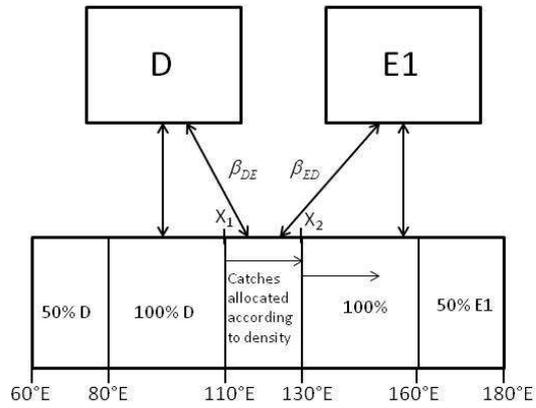
**D_E1#2:** As for D_E1#2, except that the region of overlap is shifted eastward.
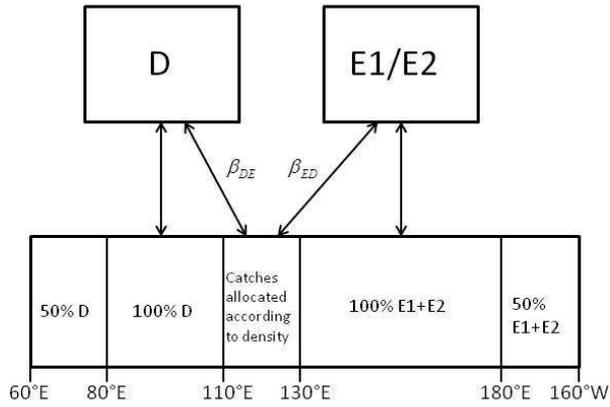


**D_E1#3:** This model is a sensitivity for D_E1#1, where East Australia (E1) and New Caledonia (E2) are considered one stock. Method used for combining BSE1+BSE2 data is described in Appendix F.

**APPENDIX E – MODEL DIAGRAMS AND CATCH ALLOCATIONS FOR A THREE-STOCK MODEL**
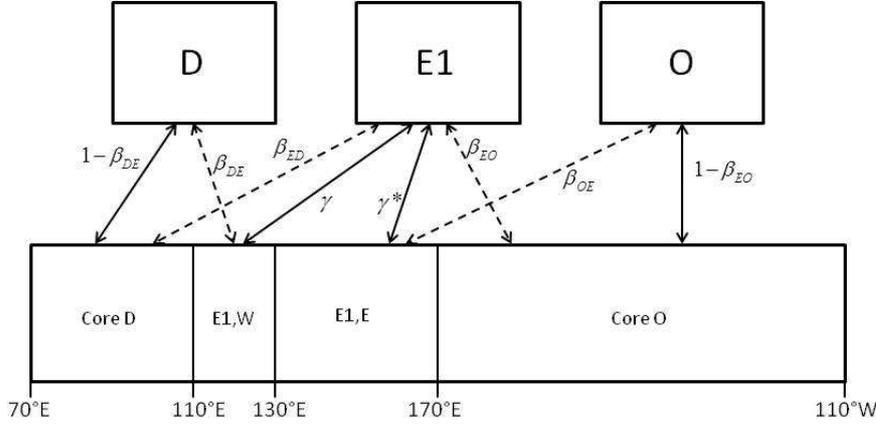


Similar to the two-stock model, the three-stock model allows for a proportion of animals from one stock to feed in a neighbouring feeding ground. In order to prevent a situation where all three stocks mix on a single feeding ground, four feeding areas are used in the model: a core D feeding area, an E1 west (E1,W) feeding area, an E1 east (E1,E) feeding area, and a core O feeding area. BSD and BSE1 mix on the core D and E1,W feeding areas, while BSE1 and BSO mix on the E1,E and core O feeding areas. It is assumed that no D animals go further east than the E1,W feeding ground, and similarly no BSO animals go further west than the E1,E feeding ground.

The feeding-ground catch allocations to the three stocks are given as follows:

$$C_y^{F,D} = \frac{(1-\beta_{DE})N_y^D}{N_y^{Core\,D}}C_y^{Core\,D} + \frac{\beta_{DE}N_y^D}{N_y^{E1,W}}C_y^{E1,W} \tag{E.1}$$

$$C_y^{F,E1} = \frac{\beta_{ED}N_y^{E1}}{N_y^{Core\,D}}C_y^{Core\,D} + \frac{\gamma N_y^{E1}}{N_y^{E1,W}}C_y^{E1,W} + \frac{\gamma^* N_y^{E1}}{N_y^{E1,E}}C_y^{E1,E} + \frac{\beta_{EO}N_y^{E1}}{N_y^{Core\,O}}C_y^{Core\,O} \tag{E.2}$$

$$C_y^{F,O} = \frac{\beta_{OE}N_y^O}{N_y^{E1,E}}C_y^{E1,E} + \frac{(1-\beta_{OE})N_y^O}{N_y^{Core\,O}}C_y^{Core\,O} \tag{E.3}$$

*Priors for the interchange parameters*

As for the two-stock model, $\beta_{DE}$ and $\beta_{DE}$ are drawn from uniform priors on the interval [0,1] with the added constraint that $\beta_{DE} + \beta_{DE} < 1$. Following similar logic, $\beta_{EO}$ and $\beta_{OE}$ are drawn from uniform priors on the interval [0,1] with the added constraint that $\beta_{EO} + \beta_{OE} < 1$. In order to ensure that the BSE1 proportions sum to 1, (i.e. $\beta_{DE} + \beta_{EO} + \gamma + \gamma^* = 1$), an approach was taken whereby $\beta_{DE}$, $\beta_{DE}$, $\beta_{EO}$ and $\beta_{OE}$ were drawn according to the above-mentioned constraints, and $\gamma$ and $\gamma^*$ were drawn from a uniform prior on the interval [0,1]. Any samples where $|1-\beta_{DE} + \beta_{EO} + \gamma + \gamma^*| > 0.01$ were discarded. The remaining samples were rescaled so that $\beta_{DE} + \beta_{EO} + \gamma + \gamma^* = 1$.

**APPENDIX F – METHOD USED TO COMBINE BSE1 AND BSE2 DATA**

**East Australia (E1) available data:**

*Absolute abundance estimate*
BSE1 absolute abundance estimate I - Noad *et al.* (2011)
A land-based survey was conducted at Point Lookout on the east coast of Australia over 8 weeks in June and July 2010. The average number of whales passing per 10h over the peak four weeks of the northward migration was 84.7 ± 3.2 whales. A correction for whales available but missed was applied using double blind counts, as well as other corrections for sighting heterogeneity (1.212 +/- 0.049, Dunlop *et al.*, 2010). Using this correction the abundance estimate for 2010 was 14,522 whales (95% CI[12] 12,777 – 16,504) (Noad *et al.*, 2011).

*Relative abundance estimates*
**Table F.1:** BSE1 Relative Abundance Index I (Noad *et al.*, 2011): A count of northward migrating whales from land-based surveys conducted at Point Lookout and two other locations. The values give the number of whales passing per 10h during four weeks of the peak migration. (M. Noad, *pers. commn*) and are as used for estimates of abundance provided by Noad *et al.*, (2008), Noad *et al.,* (2011). These data was used to in estimated annual rate of increase of 10.9%/year (95% CI = 10.5-11.3%/year) for a 24 year period (1984 to 2010) (Noad *et al.,* 2011).

| Year | 1984 | 1985 | 1986 | 1987 | 1988 | 1989 | 1990 | 1991 | 1992 |
|---|---|---|---|---|---|---|---|---|---|
| Estimate | 6.12 | 5.92 | 8.25 | 8.53 | 9.15 | 10.22 | 11.58 | 12.93 | 14.36 |
| Year | 1994 | 1996 | 1998 | 1999 | 2001 | 2002 | 2004 | 2007 | 2010 |
| Estimate | 17.75 | 20.91 | 28.45 | 27.45 | 34.67 | 37.34 | 47.11 | 70.73 | 84.7 |

**New Caledonia (E2) available data:**

2008 N=562 CV= 0.19 CI=351-772 from SH/64/SH6

**Combined data**

*Relative abundance estimates*
Assume that both E1 and E2 have the same growth rate and use the Noad *et al.* (2011) relative abundance series for the combined E1+E2 stock.

*Absolute abundance estimate*
Linearly interpolate between the 2007 and 2010 values in Table F.1 to obtain an estimate of 75.39 for 2008. To obtain an absolute estimate of abundance, the value of 84.7 was scaled to 14522 for 2010. Therefore 75.39 scales to an estimate of absolute abundance of 12 925 for 2008. The combined estimate for E1+E2 is thus 12925+562= **13487 for 2008 (CV~0.1)**.

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[12] This 95% CI was converted into a rough CV by assuming that the estimate was log-normally distributed. An approximation of the standard error of the log of the estimate was obtained by computing 0.5*(ln(16504)-ln(12777))/1.96. The resulting value of 0.065 was then taken to be the CV of the estimate.