FURTHER ASSESSMENTS OF THE SOUTHERN HEMISPHERE HUMPBACK WHALE BREEDING STOCK C AND ITS COMPONENT SUB-STOCKS

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ABSTRACT

Bayesian stock assessment results for breeding sub-stocks C1 and C2+3 are presented. Two modelling approaches are applied – one which treats the stocks independently, and another which allows mixing on the feeding grounds.

KEYWORDS: HUMPBACK WHALES, BAYESIAN ASSESSMENT

INTRODUCTION

This document reports stock assessment results for two sub-stocks of breeding stock C of the Southern Hemisphere humpback whale. These two sub-stocks are:

C1: east coast of South Africa and Mozambique

C2+3: C2 refers to whales wintering around the Comoros Islands, whereas C3 refers to whales wintering in the coastal waters of Madagascar.

Two approaches to assessing these two sub-stocks are reported. The first is a simple single stock modelling approach, along the lines of that used for breeding stocks A and G (Zerbini *et al.* 2006, Johnston and Butterworth 2006). The estimable parameters of each model are r (the intrinsic growth rate parameter) and K (the carrying capacity). The Bayesian methodology is described below. This approach assumes no mixing of the sub-stocks in question on the breeding and also (effectively) on the feeding grounds, and requires a total catch history for each sub-stock, as well as recent absolute abundance estimates for each. The availability of trend data is a major advantage, allowing the r parameter to be estimated from the data. If no trend data are available, then an r prior taken from the posterior for another similar stock can be used. There are several sources of trend data available for sub-stock C1, whereas no trend data from the breeding area for sub-stock C2+3 are available. Trend data (from the IDCR/SOWER surveys) from the combined feeding area for both sub-stocks are available. Although historic catches from the breeding grounds are available for each sub-stock, the historic catches from the feeding grounds (south of 40ºS) are for both sub-stocks combined. This simple modeling approach thus requires some method for splitting the feeding ground catches between the two sub-stocks, in order to allow a total catch series to be developed for input for each sub-stock.

The second modeling approach, which is described in detail in the Methods section below, allows for mixing of the C1 and C2+3 sub-stocks on the feeding grounds, so as to allow for a wider variety of assumptions for splitting feeding ground catches between the two sub-stocks. The two sub-stocks are assessed jointly, with now r^{C1}, r^{C2+3}, K^{C1} and K^{C2+3} becoming the estimable parameters of the model fit to various data sources from both the sub-stocks.

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DATA

Historic Catch data

There are two sources of historic catch data that relate to breeding sub-stocks C1 and C2+3.

i) Catches north of 40ºS

C1	those from "SCape", "Natal", and "Mozamb" from Allisons's database (Allison pers. commn) [note the total for each category is SCape =68, Natal=10330 and Mozamb=3995]
C2+3	those from "W Indian Ocean" from Allisons's database.

ii) Catches south of 40ºS
This series refers to catches recorded for 10ºE-60ºE and thus includes both C1 and C2+3 whales. Table 1a and Figure 1 show these three historic catch series.

Absolute abundance data

The absolute abundance data used in these analyses are presented in Table 1b. For breeding stock C1, an estimate of 5965 (CV = 0.17) for the 2003 season has been provided by Findlay (pers. commn). This is an updated estimate of the Findlay *et al*. (2004) estimate of 5811 (CV=0.15) from a series of line-transect surveys off Mozambique. The Findlay *et. al* (2004) estimate was revised in response to reviewers' comments prior to publication. The slight increase in the estimate arises from modified calculation of the radial distance of sightings from photographs (Findlay pers. commn). For breeding stock C2+3, an abundance estimate of 6328 (CV = 0.32) for the season 2001 is used. This estimate is an average of two estimates (a lower bound estimate of 5197 and an upper bound estimate of 7458) provided by Cerchio *et al*. (2006). These estimates are for sub-stock C3 – primarily for Antongil Bay in the northeast of Madagascar.

Trend information

Several sources of trend information are available for sub-stock C1. These are reported in Table 1b. These include:

i) Cape Vidal sightings per unit effort data for the 1988-2002 period (Findlay and Best 2006). These are based on shore-based surveys of northwards-migrating humpback whales at Cape Vidal, South Africa each year between 1988 and 1991, and in 2002.

ii) Four sets of relative abundance trend data from the Durban whaling ground (reported in Best 2003) are used. These are:
- Catch per unit effort 1920-1928
- Catch per unit effort 1954 – 1963 (i.e. until protection)
- Catcher sightings per unit effort 1969-1975
- Aircraft sightings per unit effort 1954-1975.

iii) CPUE data from Durban for 1910-12 (Olsen 1914).

IDCR/SOWER survey estimates (adjusted for areal comparability) provided by Branch (2006) are available for feeding ground III (10ºE-60ºE) for 1978, 1987 and 1993. These trend data clearly relate to both C1 and C2+3 animals.

From some preliminary assessments using the various sub-stock C1 data, it became apparent that it was not possible that the impact of humpback catches alone could account for the large drop in Durban CPUE for the 1920-28 period (see Table 1b). Best (pers. commn) suggests that there was a switch to other species during this period, so that more of the effort was devoted to the offshore whaling ground at the end of this time series than the beginning. Figure A1 in Appendix 1 shows these catch data for the period concerned, which indicates that there was indeed an increasing interest in other species, especially after 1922. Thus this index would have exaggerated any real decline in humpbacks. The authors therefore essentially gave this series no weight in the analyses that follow, estimating only an effective catchability coefficient to facilitate plots showing trend comparisons.

METHODS

Simple population modelling approach

The catches from the feeding grounds (catches south of 40ºS) are split 50/50 between the two sub-stocks. The IDCR/SOWER survey data are used for trend information applying equally to both sub-stocks. Because sub-stock C1 has sufficient trend information to be relatively informative in terms of estimating *r*, the *r* prior for sub-stock C1 is taken to be the relatively uninformative *r* ~ U[0, 0.106]. Due to the lack of trend data for sub-stock C2+3, the corresponding *r* prior used there is either the posterior for *r* from breeding stock A (Zerbini *et al.* 2006), or D (Johnston and Butterworth 2006), or from the simple model for sub-stock C1. The simple population modelling approach is in essence identical to the mixed modelling approach described in detail below, except that it models sub-stock C1 and C2+3 quite separately, and hence can accommodate only a limited range of assumptions for splitting the feeding ground catches between sub-stocks.

Mixed modelling approach

Breeding stock population dynamics

$$N_{y+1}^{B,C1} = N_y^{B,C1} + r^{C1} N_y^{B,C1}\left(1-\left(\frac{N_y^{B,C1}}{K^{C1}}\right)^{\mu}\right) - C_y^{C1} \quad (1)$$

$$N_{y+1}^{B,C2+3} = N_y^{B,C2+3} + r^{C2+3} N_y^{B,C2+3}\left(1-\left(\frac{N_y^{B,C2+3}}{K^{C2+3}}\right)^{\mu}\right) - C_y^{C2+3} \quad (2)$$

where

$N_y^{B,C1}$ is the number of whales in the breeding population C1 at the start of year *y*,

$N_y^{B,C2+3}$ is the number of whales in the breeding population C2+3 at the start of year *y*,

r^{C1} is the intrinsic growth rate (the maximum per capita the population can achieve, when its size is very low) for breeding population C1,

r^{C2+3} is the intrinsic growth rate for breeding population C2+3,

K^{C1} is the carrying capacity of breeding population C1,

K^{C2+3} is the carrying capacity of breeding population C2+3,

μ is the "degree of compensation" parameter; this is set at 2.39, which fixes the MSY level to MSYL = 0.6*K*, as conventionally assumed by the IWC Scientific Committee,

C_y^{C1} is the total catch (in terms of animals) in year *y* from breeding population C1, and

C_y^{C2+3} is the total catch (in terms of animals) in year *y* from breeding population C2+3.

Feeding stocks

Mixing of the breeding populations in the feeding area (defined by 10ºE – 60ºE) yields:

$$N_y^{F} = N_y^{B,C1} + N_y^{B,C2} \quad (3)$$

which we take to reflect complete mixing of sub-stocks C1 and C2+3 in the feeding area.

Catches

$$C_y^{C1} = C_y^{C1,B} + C_y^{C1,F} \quad (4)$$

$$C_y^{C2+3} = C_y^{C2+3,B} + C_y^{C2+3,F} \quad (5)$$

where

$C_y^{C1,B}$ are the catches of animals in year *y* in the C1 breeding area,

$C_y^{C1,F}$ are the catches of animals in year *y* from the C1 sub-stock in the feeding area,

$C_y^{C2+3,B}$ are the catches of animals in year *y* in the C2+3 breeding area, and

$C_y^{C2+3,F}$ are the catches of animals in year *y* from the C2+3 sub-stock in the feeding area.

Table 1a provides the $C_y^{C1,B}$ and $C_y^{C2+3,B}$ breeding area catches, but only the combined catch ($C_y^F = C_y^{C1,F} + C_y^{C2+3,F}$) for the feeding area. To split this feeding ground catch, it is assumed that the catches each year are proportional to their relative abundances in the feeding area (given that complete mixing is assumed). Thus the breakdown of feeding ground catches is calculated as follows:

$$C_y^{C1,F} = C_y^F \frac{N_y^{C1,B}}{\left(N_y^{C1,B} + N_y^{C2,B}\right)} \quad \text{and} \quad (6)$$

$$C_y^{C2+3,F} = C_y^F \frac{N_y^{C2+3,B}}{\left(N_y^{C1,B} + N_y^{C2+3,B}\right)} \quad (7)$$

<u>Bayesian estimation framework</u>

Priors

Prior distributions are defined for the following parameters:

i) $r^{C1} \sim U[0, 0.106]$ (as there are appreciable trend data to inform on *r*)

ii) $r^{C2+3} \sim$ a) r^{C1},

b) U[0, 0.106],

c) posterior from breeding stock A (Zerbini *et al.* 2006), or

d) posterior from breeding stock D (Johnston and Butterworth 2006).

iii) $\ln N_{target}^{C1,obs} * \sim U[\ln N_{target}^{C1,obs} - 4CV,\ \ln N_{target}^{C1,obs} + 4CV]$ and

iv) $\ln N_{target}^{C2+3,obs} * \sim U[\ln N_{target}^{C2+3,obs} - 4CV,\ \ln N_{target}^{C2+3,obs} + 4CV]$.

The uninformative r^{C1} and r^{C2+3} priors were 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 distributions from which target abundance estimates ($N_{target}^{C1,obs} *, N_{target}^{C2+3,obs} *$) are drawn at random are uniform on a natural logarithmic scale. The lower and upper bounds are set by four times the CV.

Using the randomly drawn vector of values of $N^{C1,obs}_{t\arg et}*$, $N^{C2+3,obs}_{t\arg et}*$, r^{C1} , and r^{C2+3}, a downhill simplex method of minimization is used to calculate K^{C1} and K^{C2} such that the model estimates of $\hat{N}^{C1}_{t\arg et}$ and $\hat{N}^{C2+3}_{t\arg et}$ are identical to the randomly drawn values $N^{C1,obs}_{t\arg et}*$ and $N^{C2+3,obs}_{t\arg et}*$.

For each simulation, using the r^{C1} , r^{C2+3} and calculated K^{C1} and K^{C2+3} values, a negative log likelihood is then computed by comparing the population model to observed data - these being the target abundance estimates from the breeding grounds (treated as absolute abundance estimates), CPUE data from the breeding grounds for C1, aircraft SPUE data for C1, relative abundance trend data from the breeding grounds for C1 (Cape Vidal data), and IDCR/SOWER relative abundance trend data from the combined feeding area. These components of the negative log likelihood are calculated as follows.

The model treats the CPUE estimates as relative indices of abundance. It is assumed that the observed relative abundance index is log-normally distributed about its expected value:

$$I^{C1}_y = q^A \hat{N}^{B,C1}_y e^{\varepsilon_y} \tag{8}$$

where

I^{C1}_y	is either the survey-based relative abundance or CPUE index for year *y* for breeding sub-stock C1,
q^{C1}	is the catchability coefficient for that index for breeding sub-stock C1,
$\hat{N}^{B,C1}_y$	is the model estimate of population size at the start of year *y* for breeding sub-stock C1, and
ε_y	is from $N(0,\sigma^2_{B,C1})$.

The model also treats the IDCR/SOWER abundance estimates as relative indices as follows. It is assumed that the observed abundance index is log-normally distributed about its expected value:

$$I_y = q_{IDCR} \hat{N}^F_y e^{\eta_y} \tag{9}$$

where

I_y	is the IDCR/SOWER abundance estimate for year *y* and the combined feeding area,
q_{IDCR}	it the multiplicative bias of the IDCR/SOWER abundance estimate for the combined feeding stock,
$\hat{N}^F_y$	is the model estimate of population size at the start of year *y* in the combined feeding stock, and
η_y	is from $N(0,(\sigma_{IDCR})^2)$.

The model treats the aircraft SPUE abundance estimates slightly differently as follows, in particular to take proper account of zero sightings in some years. A Poisson distribution is assumed. The expected number of sightings in year *y* is:

$$\hat{n}_y = q_{SPUE} \hat{N}^{B,C1}_y E_y \tag{10}$$

where

$\hat{N}_y^{B,C1}$ is the model estimate of population size at the start of year y for breeding sub-stock C1, and

E_y is the aircraft searching effort in year y.

The associated "catchability" coefficient is calculated as follows:

$$q_{SPUE} = \frac{\sum_y n_y}{\sum_y \hat{N}_y^{B,C1}.E_y} \tag{11}$$

where

n_y is the observed number of whale sightings in year y.

The contributions of the various data to the negative of the log-likelihood function are then given by:

$$\begin{aligned}
-\ln L = &\sum_S \{w_{cpue,S} [n_{CPUE,S}^{C1} \ln \sigma_{CPUE,S}^{C1} + \frac{1}{2{\sigma_{CPUE,S}^{C1}}^2} \sum_y \left(\ln I_{CPUE,S,y}^{C1} - \ln q_{CPUE,S}^{C1} - \ln \hat{N}_y^{B,C1}\right)^2]\} + \\
&w_{IDCR} [n_{IDCR} \ln \sigma_{IDCR} + \frac{1}{2\sigma_{IDCR}^2} \sum_y \left(\ln I_{IDCR,y} - \ln q_{IDCR} - \ln \hat{N}_y^F\right)^2] + \\
&w_{SPUE} \left[\sum_y \{q_{SPUE} \hat{N}_y^{B,C1} E_y - n_y \ln(q_{SPUE} \hat{N}_y^{B,C1} E_y)\} \right] \\
&\sum_A \ [\frac{1}{2CV^2} \left(\ln N_Y^{A,obs} - \ln \hat{N}_Y^{B,A}\right)^2]
\end{aligned}$$

where

$w_{cpue,S}$ is the weight given to the CPUE data series S,

w_{SPUE} is the weight given to the SPUE data series (for C1),

w_{IDCR} is the weight given to the IDCR/SOWER survey data,

A is sub-stock C1 or C2+3.

The σ parameters are the residual standard deviations which are estimated in the fitting procedure by their maximum likelihood values:

$$\hat{\sigma}_{CPUE}^{C1} = \sqrt{1/n \sum_y \left(\ln I_{CPUE,y}^{C1} - \ln q_{CPUE}^{C1} - \ln \hat{N}_y^{B,C1}\right)^2} \quad \text{for CPUE data} \tag{12}$$

and

$$\hat{\sigma}_{IDCR} = \sqrt{1/n \sum_y \left(\ln I_{IDCR,y} - \ln q_{IDCR} - \ln \hat{N}_y^F\right)^2} \quad \text{for feeding ground IDCR/SOWER survey data}$$

where

n is the number of data points in the CPUE/survey series, and

q is the multiplicative bias/catchability coefficient, estimated by its maximum likelihood value:

$$\ln \hat{q}^{C1} = 1/n \sum_y \left(\ln I_y^{C1} - \ln \hat{N}_y^{B/F,C1} \right) \tag{13}$$

(This is a short cut to avoid integrating over priors for the q's and σ^2's, and in fact corresponds to the assumption that these priors are uniform in log-space and proportional to σ^{-3} respectively (Walters and Ludwig 1994).)

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) as described in Zerbini (2004). For a vector of parameter values θ_i, the (importance function modified) likelihood of the data associated with this vector of parameters (L) as described above is calculated and stored. This process is repeated until an initial sample of n_1 θ_i s is generated. This sample is then resampled with replacement n_2 times with probability equal to weight w_j, where:

$$w_j = \frac{L\ (\theta_j / data)}{\sum_{j=1}^{n1} L\ (\theta_j / data)} \tag{14}$$

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

Values of n_1 (original number of simulations) are 100 000 and the value of n_2 (number of resamples) is 1000. Tests showed that no sample contributed more than 0.05% of the total weight, and that at least 94% of the resamples were unique values.

Nmin constraints

N_{min} constraints of 248 and 496 whales are imposed for sub-stocks C1 and C2+3 respectively. These values are 4 times the number of haplotypes estimated by Rosenbaum *et al.* (2006) for these sub-stocks.

RESULTS AND DISCUSSION

Simple Single stock analyses

Tables 2a and b report the simple stock assessment results for sub-stocks C1 and C2+3 respectively. The sub-stock C1 posterior median estimate of current depletion is 0.74*K*, whereas for sub-stock C2+3 current depletion is estimated to be somewhat more optimistic, and ranges between 0.84-0.93*K* for the three scenarios explored here. Figure 2a shows the sub-stock C1 model fit to the trend information. The model appears to fit the trend data well, except for the last (2002) data point of the Cape Vidal SPUE series. [Remember the model actually excludes the CPUE1 (1920-1928) Durban CPUE data in the fit for reasons detailed above.] Figure 2b shows the C1 estimated population trajectories, which evidence fairly narrow 90% confidence intervals. Figure 3a shows the sub-stock C2+3 model fit to the trend data (here only the IDCR/SOWER data series). Figure 3b shows that the C2+3 population trajectories are estimated with a much wider 90% confidence interval than for the C1 sub-stock model.

Mixed stock analyses

Results for the four mixed-model stock assessments are reported in Tables 3a-d. Figures 4-7 show mixed-model results for the $r^{C2+3} = r^{C1}$~U[0, 0.106] scenario. The posterior median estimates of current depletion for sub-stock C1 are all 0.82*K*, and are insensitive to the prior assumed for the sub-stock C2+3 r parameter. This estimate (0.82*K*) is more optimistic than that of the simple sub-stock C1 model (0.74*K*). The results for sub-stock C2+3 are highly dependant on the assumption made for the r

prior. Posterior median estimates of current depletion for C2+3 range from 0.57*K* (r^{C2+3} ~ U[0, 0.106]) to 1.00*K* ($r^{C2+3} = r^{C1}, r^{C1}$ ~U[0, 0.106] and r^{C2+3} ~ post (BS D)). Although the 90% probability intervals for C1 estimates are generally quite narrow, for the C2+3 estimates these are very wide, indicating that there is not sufficient data for C2+3 to assess this sub-stock with much certainty.

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Table 1a: Historic catch series for sub-stocks C1 and C2+3 (Allison, pers. commn).

Season	C1 Breeding grounds	C2+3 Breeding grounds	C1+2+3 Feeding grounds	Season	C1 Breeding grounds	C2+3 Breeding grounds	C1+2+3 Feeding grounds	Season	C1 Breeding grounds	C2+3 Breeding grounds	C1+2+3 Feeding grounds
1900	0	0	0	1926	124	0	0	1952	111	0	208
1901	0	0	0	1927	86	0	0	1953	89	0	66
1902	0	0	0	1928	62	0	0	1954	28	0	50
1903	0	0	0	1929	99	0	4	1955	49	0	28
1904	0	0	0	1930	134	0	150	1956	36	0	4
1905	0	0	0	1931	72	0	2	1957	34	0	66
1906	0	0	0	1932	307	0	38	1958	39	0	120
1907	0	0	0	1933	162	0	54	1959	38	0	152
1908	104	0	0	1934	514	0	554	1960	36	0	72
1909	149	0	0	1935	418	0	1870	1961	40	4	28
1910	632	0	0	1936	300	0	2684	1962	38	1	74
1911	1580	0	0	1937	242	1223	780	1963	38	0	40
1912	2313	25	0	1938	177	1752	0	1964	3	3	48
1913	1805	0	0	1939	200	1240	4	1965	2	1	76
1914	830	0	0	1940	176	0	0	1966	0	0	196
1915	334	0	0	1941	79	0	0	1967	8	8	66
1916	94	0	0	1942	156	0	0	1968	0	0	0
1917	7	0	0	1943	80	0	0	1969	0	0	0
1918	9	0	0	1944	115	0	0	1970	0	0	0
1919	91	0	0	1945	116	0	0	1971	0	0	0
1920	148	0	0	1946	93	0	0	1972	0	0	0
1921	251	0	0	1947	89	0	0	1973	1	0	0
1922	285	0	0	1948	182	0	34	1974	0	0	0
1923	183	0	0	1949	190	1333	396	1975	0	0	0
1924	187	0	0	1950	151	714	74				
1925	372	0	0	1951	103	0	212				

Table 1b

Absolute abundance estimates used in analyses for sub-stocks C1 and C2+3

Breeding sub-stock	**Abundance estimate**	**Year applicable**	**Source**
C1	5965 (CV = 0.17)	2003	Findlay pers. commn
C2+3	6328 (CV = 0.32)	2001	Cerchio *et al.* (2006)

Table 1b: Relative abundance trend data for sub-stock C1. [Note that the IDCR/SOWER data relate to the combined feeding area for C1+2+3, and have been adjusted to correspond to the same northern boundary for comparability.]

Year	**Cape Vidal (Findlay and Best 2006)**	**Year**	**IDCR/ Sower**	**Year**	**Olsen (1914)**	**Year**	**CPUE from Durban 1920-28**	**Year**	**CPUE from Durban 1954-63**	**Year**	**CPUE from Durban 1969-75**	**Year**	**Aircraft SPUE and effort from Durban 1954-75**		
													SPUE	**N**	**Effort**
1988	358	**1979**	1043	**1910**	0.9057	**1920**	1.772	**1954**	0.404	**1969**	0.404	**1954**	2.868	5	174.35
1989	249	**1987**	926	**1911**	0.8499	**1922**	3.333	**1955**	0.564	**1970**	0.564	**1957**	0	0	325.49
1990	359	**1993**	2391	**1912**	0.4884	**1923**	1.377	**1956**	0.406	**1971**	0.406	**1958**	0	0	423.40
1991	587					**1924**	1.655	**1957**	0.437	**1972**	0.437	**1959**	0.223	1	448.58
2002	1673					**1925**	1.151	**1958**	0.439	**1973**	0.439	**1960**	0	0	585.00
						1926	0.895	**1959**	0.406	**1974**	0.406	**1961**	1.289	9	698.22
						1927	0.553	**1960**	0.381	**1975**	0.381	**1962**	0.257	2	779.71
						1928	0.459	**1961**	0.408			**1963**	0.180	2	1119.99
								1962	0.377			**1964**	0.197	2	1016.33
								1963	0.343			**1965**	0	0	1102.26
												1966	1.336	13	972.86
												1967	0.710	6	844.95
												1968	0.294	2	681.36
												1969	1.254	9	717.87
												1970	0.536	4	745.83
												1971	0.426	3	704.31
												1972	0.966	7	724.51
												1973	1.720	11	639.23
												1974	1.514	8	528.32
												1975	1.871	10	534.35

Table 2a: Simple stock C1 assessment results (posterior medians and 5th and 95th percentiles in parenthesis).

	BS C1
***r* prior** **Historic catch** **Recent abundance** **Trend information**	**U ~ [0, 0.106]** **50% of catches south of 40ºS** **5965 (2003)** **all 5 trends, Durban 1920-28 excluded**
r	0.071 [0.047; 0.094]
K	9,879 [8,759; 11,743]
N_{min}	689 [444; 1,268]
N_{2006}	7,329 [5,791; 8,394]
N_{min}/K	0.070 [0.049; 0.110]
N_{2006}/K	0.742 [0.509; 0.935]
N_{2020}/K	0.966 [0.786; 0.998]
N_{2040}/K	0.999 [0.971; 1.000]

Table 2b: Simple stock C2+3 assessment results (posterior medians and 5th and 95th percentiles in parenthesis).

	BS C2+3	**BS C2+3**	**BS C2+3**
***r* prior** **Historic catch** **Recent abundance** **Trend information**	r^E **= post (A)** **50% of catches south of 40ºS** **6328 (2001)** **IDCR/SOWER**	r^E **= post (C1)** **50% of catches south of 40ºS** **6328 (2001)** **IDCR/SOWER**	r^E **= post (C1)** **50% of catches south of 40ºS** **6328 (2001)** **None**
r	0.060 [0.027; 0.083]	0.066 [0.045; 0.084]	0.068 [0.044; 0.089]
K	8,390 [7,715; 11,427]	8175 [7666; 10012]	8,273 [7,676; 11,235]
N_{min}	905 [531; 4,954]	763 [519; 4638]	924 [526; 6,988]
N_{2006}	7,041 [4,779; 9,952]	7149 [5107; 9766]	7,476 [5,354; 11,147]
N_{min}/K	0.108 [0.068; 0.440]	0.094 [0.067; 0.466]	0.111 [0.068; 0.629]
N_{2006}/K	0.837 [0.519; 1.000]	0.882 [0.608; 1.000]	0.931 [0.637; 1.000]
N_{2020}/K	0.975 [0.721; 1.000]	0.986 [0.877; 1.000]	0.994 [0.884; 1.000]
N_{2040}/K	0.999 [0.906; 1.000]	1.000 [0.987; 1.000]	1.000 [0.988; 1.000]

Table 3a: Mixed-sub-stock modelling stock assessment results (posterior medians and 5th and 95th percentiles in parenthesis). Results for $r^{C2+3} = r^{C1}, r^{C1}$~U[0, 0.106].

	BS C1		BS C2+3
***r* prior**	**U[0, 0.106]**		$r^{C2+3} = r^{C1}, r^{C1}$~U[0, 0.106]
Historic catch	**Feeding grounds split proportional to abundance**		**Feeding grounds split proportional to abundance**
Recent abundance	**5965 (2003)**		**6328 (2001)**
Trend information	**5 trends from breeding grounds (Durban 1920-28 excluded**	**IDCR/SOWER trend for combined feeding ground**	
r	0.089 [0.069; 0.102]		0.089 [0.069; 0.102]
K	8,514 [8,133; 9,439]		10,272 [8,970; 14,044]
N_{min}	298 [252; 563]		2,769 [941; 6,665]
N_{2006}	7,036 [5,802; 7,687]		10,263 [8,734; 14,044]
N_{min}/K	0.035 [0.030; 0.060]		0.270 [0.101; 0.476]
N_{2006}/K	0.823 [0.625; 0.939]		1.000 [0.959; 1.000]
N_{2020}/K	0.991 [0.993; 0.999]		1.000 [0.997; 1.000]
N_{2040}/K	1.000 [0.998; 1.000]		1.000 [1.000; 1.000]

Table 3b: Mixed-sub-stock modelling stock assessment results (posterior medians and 5th and 95th percentiles in parenthesis). Results for r^{C2+3}~U[0, 0.106], i.e. no longer equal to r^{C1}.

	BS C1		BS C2+3
***r* prior**	**U[0, 0.106]**		U[0, 0.106]
Historic catch	**Feeding grounds split proportional to abundance**		**Feeding grounds split proportional to abundance**
Recent abundance	**5965 (2003)**		**6328 (2001)**
Trend information	**5 trends from breeding grounds (Durban 1920-28 excluded**	**IDCR/SOWER trend for combined feeding ground**	
r	0.089 [0.073; 0.102]		0.024 [0.002; 0.095]
K	8,450 [8,061; 9,161]		13,735 [9,622; 20,607]
N_{min}	307 [255; 493]		3,740 [1,354; 8,253]
N_{2006}	7,049 [5,813; 7,651]		8,384 [4,812; 13,213]
N_{min}/K	0.037 [0.031; 0.054]		0.262 [0.128; 0.440]
N_{2006}/K	0.828 [0.647; 0.938]		0.575 [0.308; 1.000]
N_{2020}/K	0.991 [0.946; 0.999]		0.707 [0.332; 1.000]
N_{2040}/K	1.000 [0.999; 1.000]		0.862 [0.364; 1.000]

Table 3c: Mixed-sub-stock modelling stock assessment results (posterior medians and 5th and 95th percentiles in parenthesis). Results for r^{C2+3} ~ post (BS A).

	BS C1		**BS C2+3**
***r* prior**	**U[0, 0.106]**		r^{C2+3} ~ post (BS A)
Historic catch	**Feeding grounds split proportional to abundance**		**Feeding grounds split proportional to abundance**
Recent abundance	**5965 (2003)**		**6328 (2001)**
Trend information	**5 trends from breeding grounds (Durban 1920-28 excluded**	**IDCR/SOWER trend for combined feeding ground**	
r	0.089 [0.072; 0.104]		0.051 [0.013; 0.089]
K	8,508 [8,069; 9,230]		11,550 [9,537; 16,928]
N_{min}	315 [255; 511]		2,649 [1,021; 6,851]
N_{2006}	7,031 [5,875; 7,718]		9,699 [5,825; 13,630]
N_{min}/K	0.037 [0.031; 0.057]		0.233 [0.103; 0.423]
N_{2006}/K	0.824 [0.649; 0.946]		0.883 [0.415; 1.000]
N_{2020}/K	0.990 [0.947; 0.999]		0.975 [0.500; 1.000]
N_{2040}/K	1.000 [0.999; 1.000]		0.998 [0.631; 1.000]

Table 3d: Mixed-sub-stock modelling stock assessment results (posterior medians and 5th and 95th percentiles in parenthesis). Results for r^{C2+3} ~ post (BS D).

	BS C1		**BS C2+3**
***r* prior**	**U[0, 0.106]**		r^{C2+3} ~ post (BS D)
Historic catch	**Feeding grounds split proportional to abundance**		**Feeding grounds split proportional to abundance**
Recent abundance	**5965 (2003)**		**6328 (2001)**
Trend information	**5 trends from breeding grounds (Durban 1920-28 excluded**	**IDCR/SOWER trend for combined feeding ground**	
r	0.089 [0.071; 0.102]		0.090 [0.001; 0.105]
K	8,502 [8,108; 9,284]		10,799 [8,894; 20,270]
N_{min}	301 [251; 506]		3,011 [1,179; 7,826]
N_{2006}	6,954 [5,707; 7,678]		10,005 [6,017; 14,030]
N_{min}/K	0.035 [0.030; 0.055]		0.276 [0.122; 0.475]
N_{2006}/K	0.817 [0.630; 0.936]		1.000 [0.323; 1.000]
N_{2020}/K	0.989 [0.939; 0.999]		1.000 [0.323; 1.000]
N_{2040}/K	1.000 [0.998; 1.000]		1.000 [0.323; 1.000]

Figure 1: Historic catch series for sub-stocks C1 and C2+3.

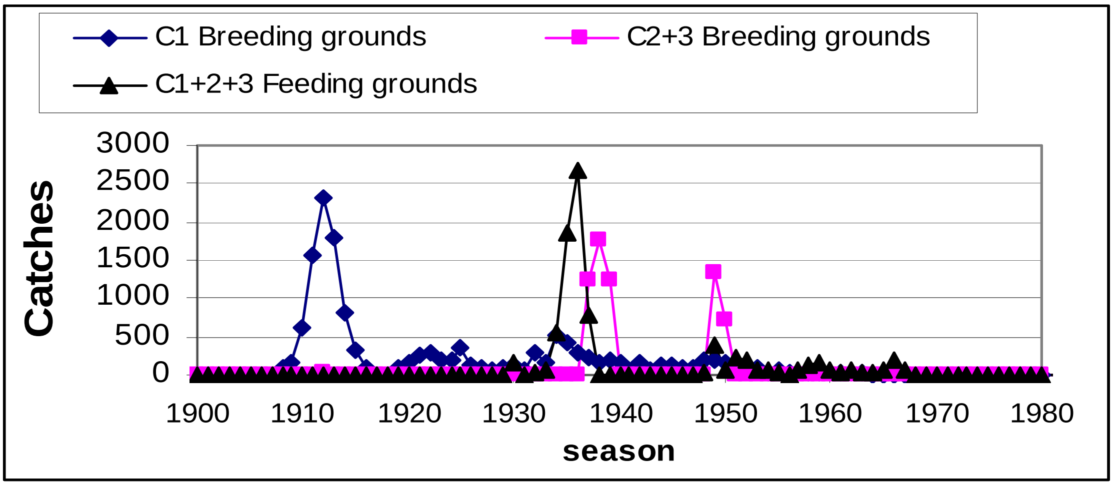


Figure 2a: Simple stock model fit to C1 trend information. The CPUE1, CPUE2 and CPUE3 trends here refer to the Durban CPUE trends for 1920-1928, 1954-1963 and 1969-1975 respectively, reported in Table 1b, as are the other relative abundance indices tabulated below. The vertical line shows 2006.

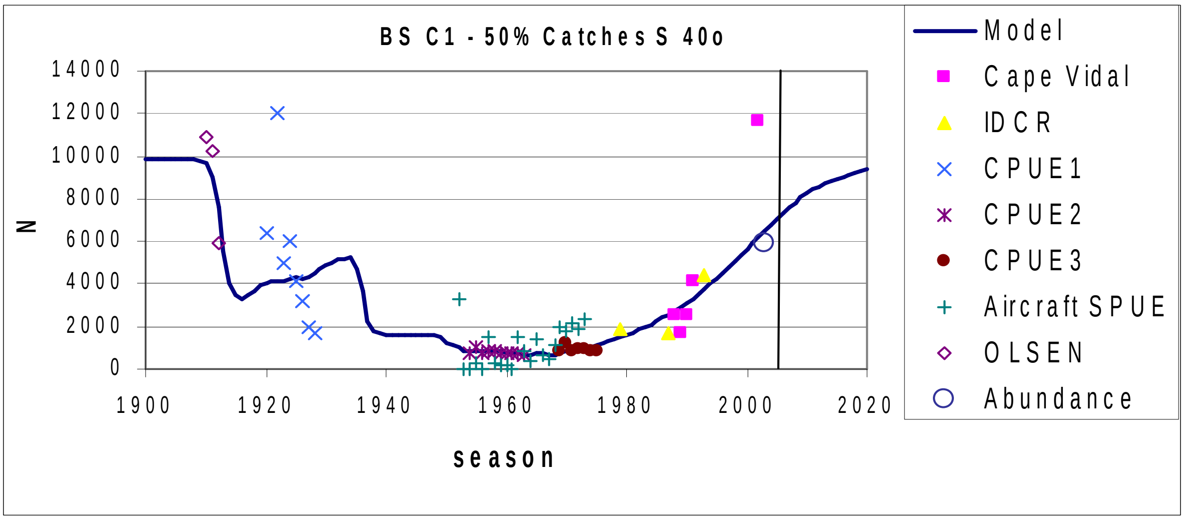


Figure 2b: Simple stock assessment C1 population trajectories, showing the median and 90% probability intervals.

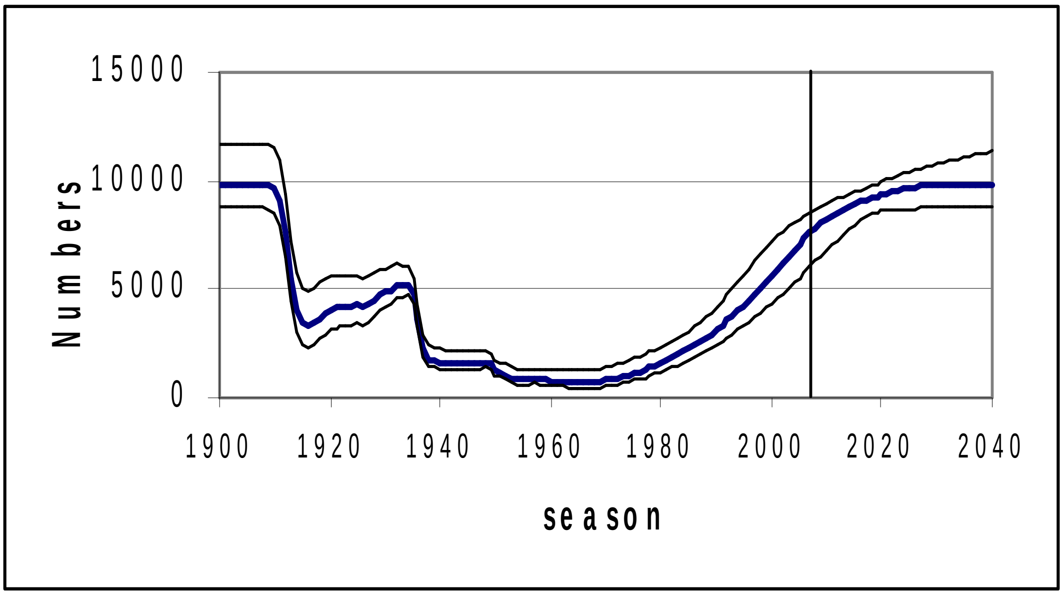


Figure 3a: Simple assessment of sub-stock C2+3 population fit to data, where r^{C2+3} ~ post (C1). The vertical line shows 2006.

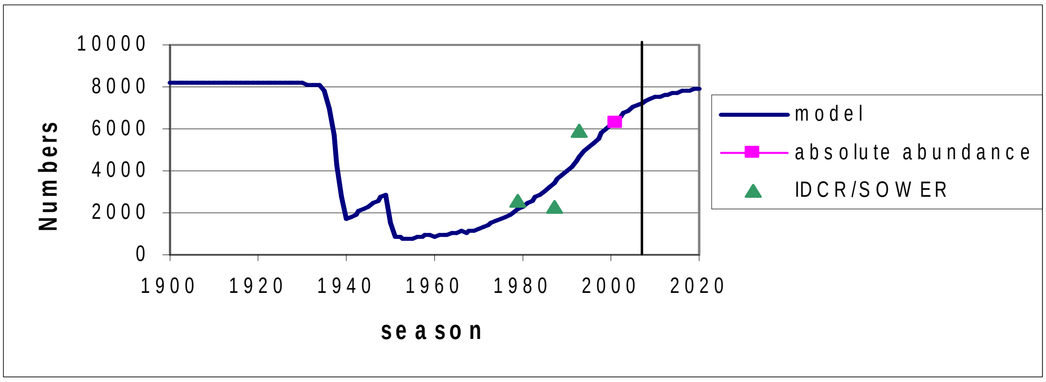


Figure 3b: Simple stock assessment C2+3 population trajectories, showing the median and 90% probability intervals.

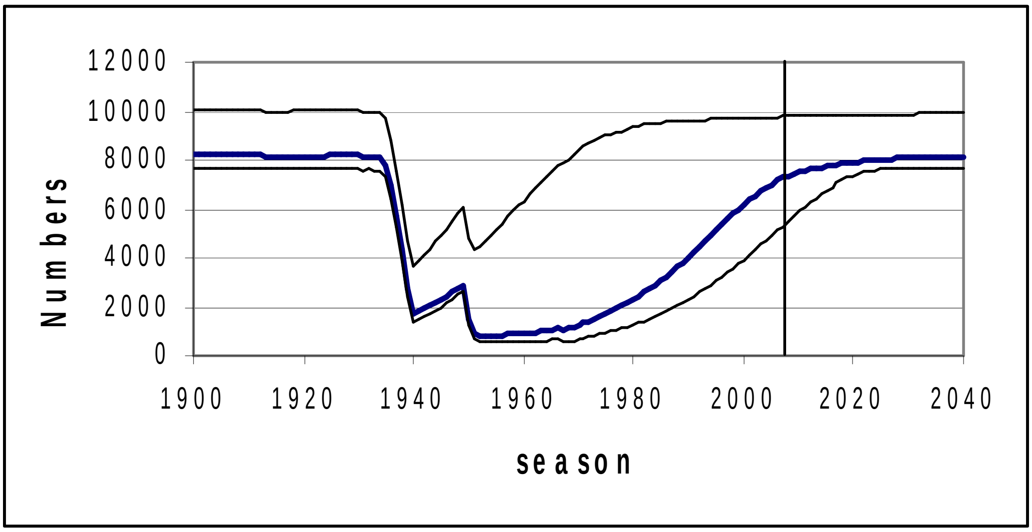


Figure 4a: Mixed model ($r^{C2+3} = r^{C1}$ ~U[0, 0.106]) fit to C1 breeding ground trend and absolute abundance data. The CPUE1, CPUE2 and CPUE3 trends here refer to the Durban CPUE trends for 1920-1928, 1954-1963 and 1969-1975 respectively, reported in Table 1b, as are the other relative abundance indices tabulated below. The vertical line shows 2006.

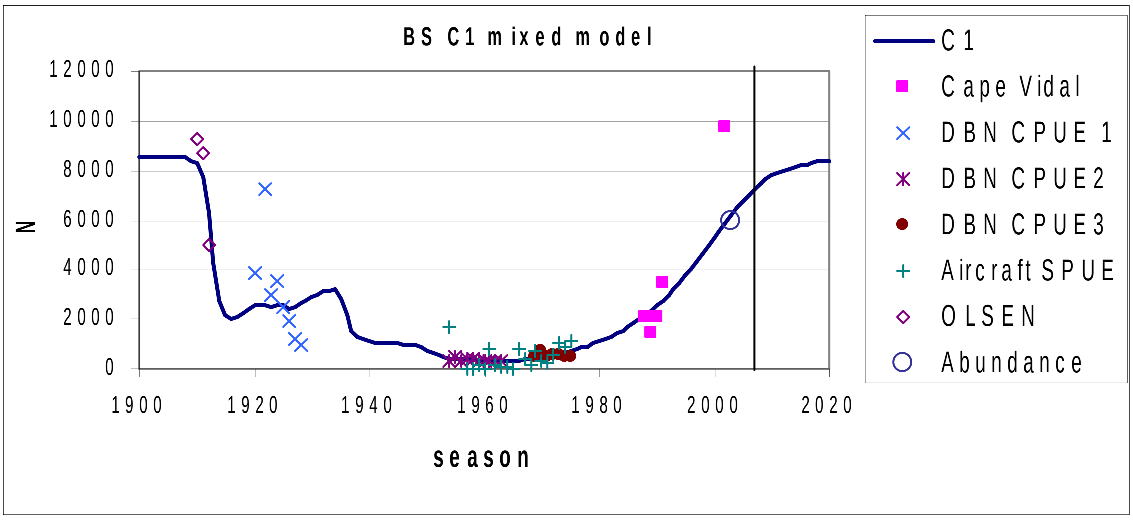


Figure 4b: Mixed model ($r^{C2+3} = r^{C1}$ ~U[0, 0.106]) fit to C2+3 breeding ground absolute abundance data.

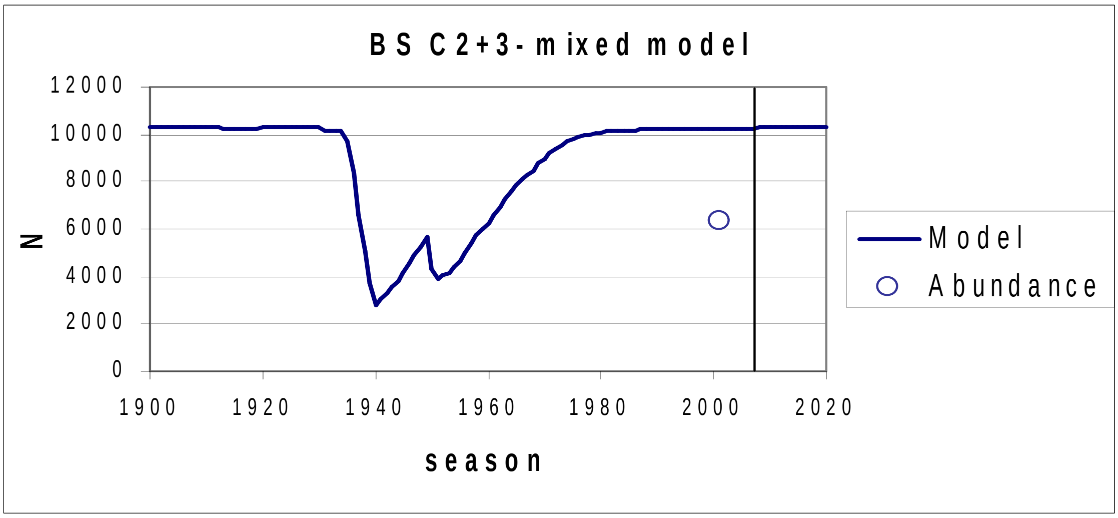


Figure 4c: Mixed model ($r^{C2+3} = r^{C1}$ ~U[0, 0.106]) fit to C1+2+3 feeding ground numbers.

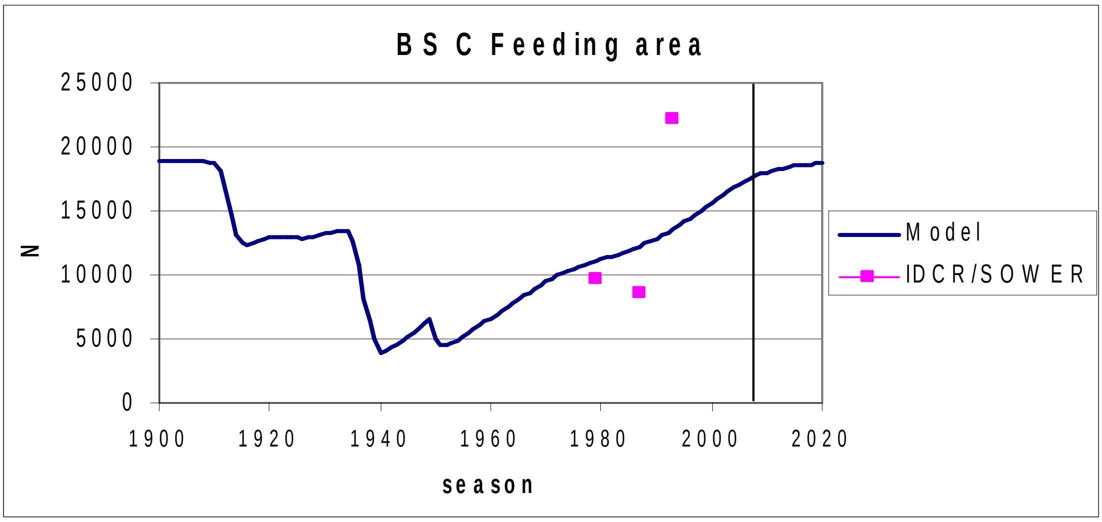


Figure 5a: Mixed model ($r^{C2+3} = r^{C1}$ ~U[0, 0.106]) estimates of C1 and C2+3 sub-stock population size, and C1+2+3 total population size – median plus 90% probability intervals shown.

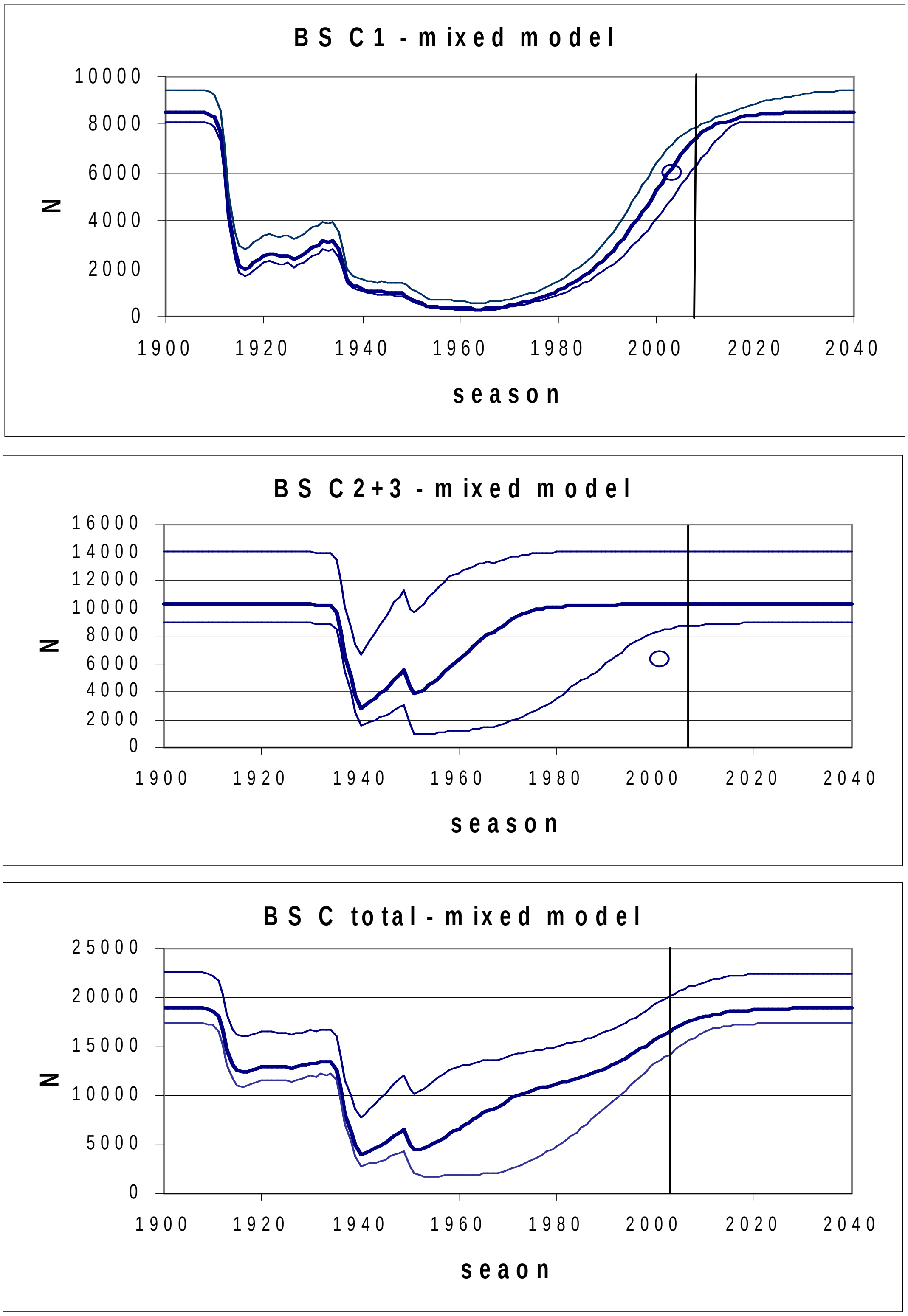
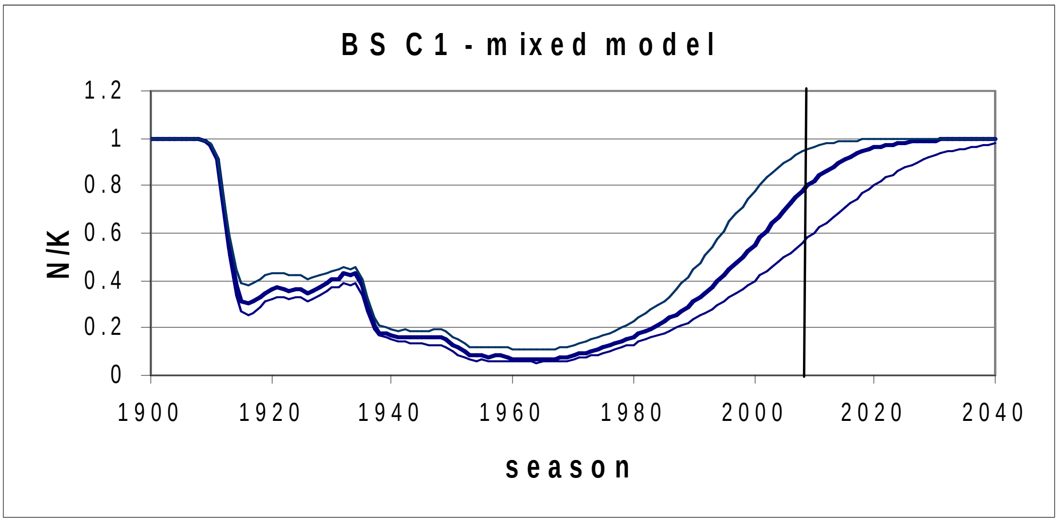
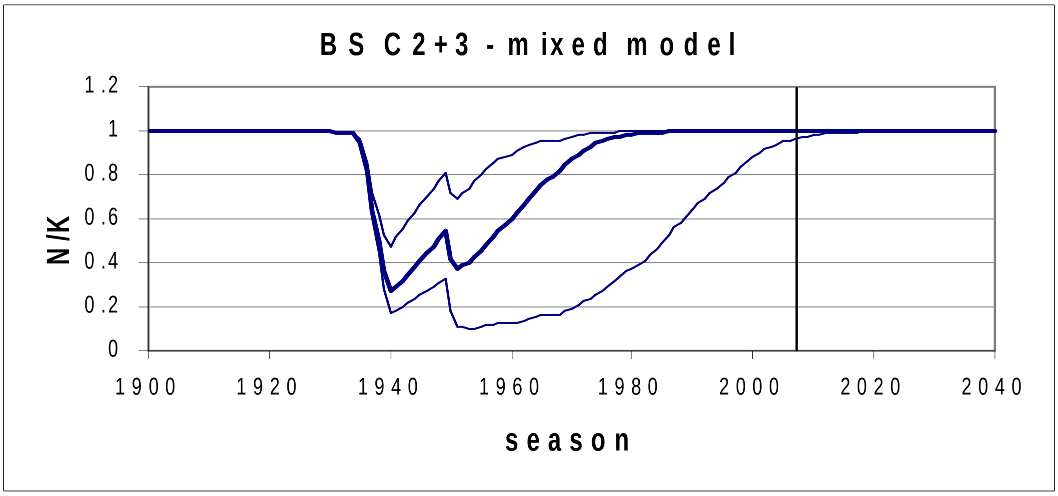


Figure 5b: Mixed model ($r^{C2+3} = r^{C1}$ ~U[0, 0.106]) estimates of C1 and C2+3 sub-stock population size relative to pristine, and C1+2+3 total population size relative to pristine – median plus 90% probability intervals shown.





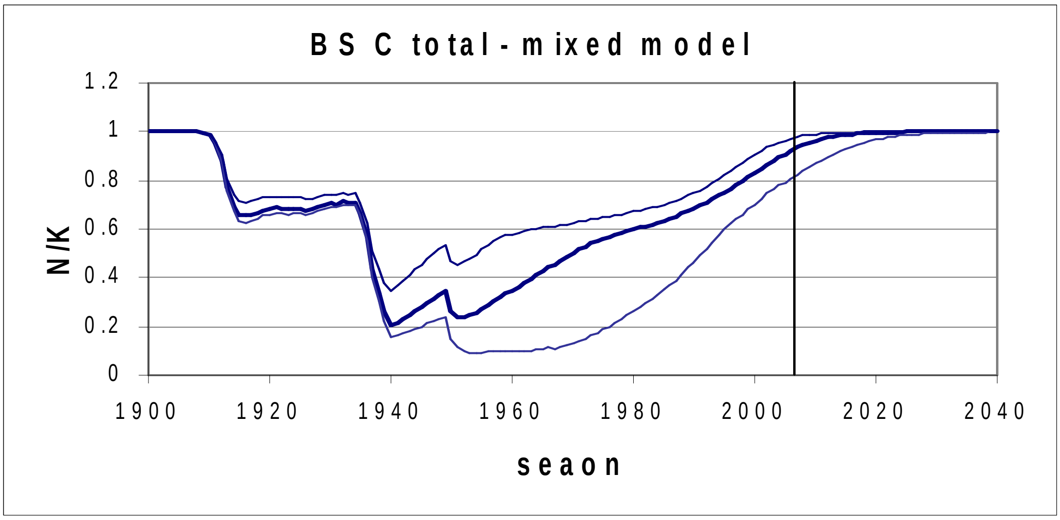


Figure 6: Estimated relative proportions of sub-stocks C1 and C2+3 on the feeding grounds over time for the mixed model ($r^{C2+3} = r^{C1}$ ~U[0, 0.106]).

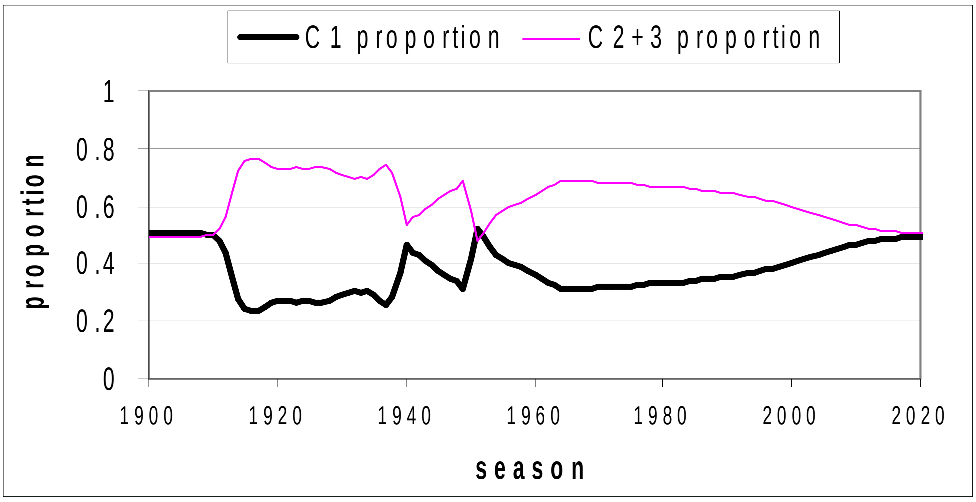
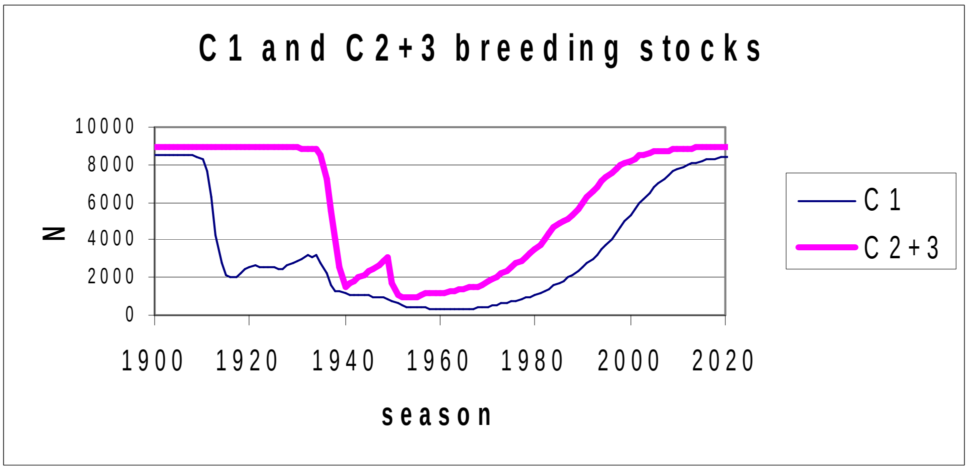


Figure 7: Comparison between the mixed model ($r^{C2+3} = r^{C1}$ ~U[0, 0.106]) estimated population trends of C1 and C2+3.



Appendix 1:

Figure A1.1: Baleen whale catches from the Durban whaling grounds 1920-1928 (Best pers. commn).