Table 1

Estimated mixing proportions for two different definitions of boundaries in the feeding areas. Round and square brackets are standard errors and 95%CIs, respectively.

Feeding area	Sample size	BSD	BSE1	Oceania
(a) 2013 definition				
70°E-140°E	247	0.8548 (0.0349)	0.1452 (0.0349)	0
		[0.772, 0.911]	[0.228, 0.089]	
140°E-160°E	56	0.0828 (0.0460)	0.9172 (0.0460)	0
		[0.027, 0.228]	[0.772, 0.973]	
160°E-150°W	146	0	0.3235 (0.0742)	0.6765 (0.0742)
			[0.197, 0.482]	[0.518, 0.803]
150°W -110°W	20	0	0.0000 (0.0000)	1.0000 (0.0000)
			[0.000, 0.000]	[1.000, 1.000]
(b) 2014 definition				
70°E-110°E	188	0.9213 (0.0332)	0.0787 (0.0332)	0
		[0.827, 0.966]	[0.034 0.173]	
110°E-130°E	43	0.8974 (0.0855)	0.1026 (0.0855)	0
		[0.586, 0.982]	[0.018, 0.414]	
130°E-170°E	120	0	0.6802 (0.0666)	0.3198 (0.0666)
			[0.539, 0.795]	[0.205, 0.461]
170°E -110°W	118	0	0.1080 (0.0654)	0.8920 (0.0654)
			[0.031, 0.314]	[0.686, 0.969]

Table 2

Number of samples (mtDNA sequences) available by 10° longitude sectors.

Sector	Sample size
35°-40°E	17
40°-50°E	40
50°-60°E	27
60°-70°E	22
70°-80°E	32
80°-90°E	63
90°-100°E	50
100°-110°E	43
110°-120°E	27
120°-130°E	16
130°-140°E	16
14°0-150°E	36
150°-160°E	20
160°-170°E	48
170°E-180°	28
180°-170°W	23
170°-160°W	44
160°-150°W	3
150°-140°W	2
140°-130°W	9
130°-120°W	9

Appendix 3

FINAL RESULTS FOR THE FINAL 'BASE CASE' THREE-STOCK BSD, BSE1 AND BSO MODEL, WITH SENSITIVITY RUNS

A. Ross-Gillespie, D.S. Butterworth and K. Findlay

INTRODUCTION

Paper SC/65b/SH04rev and SC/65b/SH04app presented to the meeting included a three-stock model with mixing of breeding stocks in the feeding grounds, which is referred to below as the 'original model'. The sub-committee decided to focus on this three-stock approach and also considered an 'alternative' model with a simpler mixing foundation. The sub-committee agreed to use the alternative three-stock model presented in Fig. 1 (with one interchange parameter) as the base case (hereafter referred to as the base case model) as there were several major concerns regarding the original, six interchange parameter, three-stock model in Fig. 2, including the following.

(1) Constraints had to be placed on the six interchange parameters to prevent 'majority cross-overs' (i.e. a scenario where the majority of one stock crosses over into a neighbouring feeding area while the neighbouring stock does the same). These constraints resulted in non-uniform priors that can under-sample high values for interchange rates, which led to inefficient computations when the value for an interchange parameter was likely to be high.

(2) Many of the interchange parameters, as well as the BSO growth rate parameter, seemed to be poorly estimated.
(3) The relatively high number of parameters to be estimated in this model led to severe sampling inefficiency.

The alternative (now base case) three-stock model was on the other hand much simpler, with only one interchange parameter that needed to be estimated (namely the proportion of BSE1 whales that feed in the western feeding area). Sampling efficiency remained a problem since parameters had to be estimated for each of the three breeding stocks, although to a far lesser extent than for the original model. Although importance functions had been implemented to address the issue of sampling efficiency, these did not improve the efficiency of the original model greatly.

However it should be noted that the original three-stock model did better capture biological reality, and as such should revisited in future when further genetic information on mixing proportions in Antarctic feeding grounds is available to inform the estimation of the interchange parameters better.

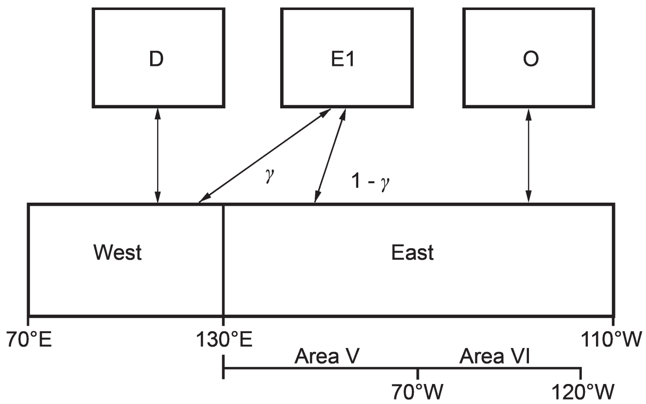

Fig. 1. Diagrammatic representation of the base case three-stock model. The traditional Area V and Area VI have been marked for reference.

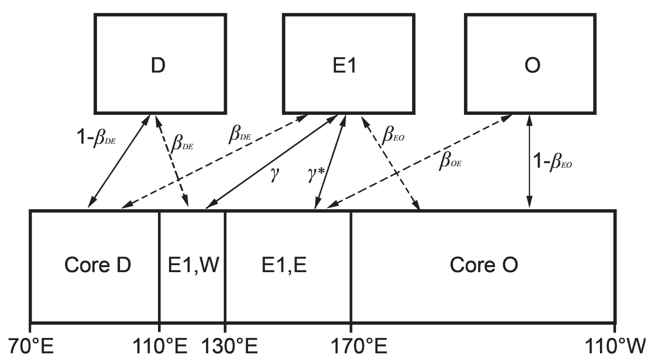

Fig. 2. Diagrammatic representation of the original three-stock model.

MODEL RUNS

In the process of multiple model runs, both intersessionally and at this meeting, the sub-committee identified the following assumptions for the final base case model.

(1) A BSO N_{min} constraint > 3*33.
(2) New Zealand catches (i.e. catches from Rakiura, Kaikoura, Cook Straight, Great Barrier Island and Whangamumu land-stations and three catches specified to New Zealand) are allocated to BSE1 and BSO in proportion to the relative population sizes of these breeding stocks.
(3) 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 abundances estimates for BSE1; and the Constantine *et al.* (2012) mark-recapture data for Oceania.
(4) An uninformative uniform prior of U[ln15,000, ln40,000] is used for the log of the target abundance estimate for BSD.

Fig. 3 illustrates the importance functions implemented, which serve to improve the sampling efficiency of the model. For the base case model, importance functions were utilised for r^D, r^{E1}, r^O and γ. For the original model, importance functions were only utilised for r^D and r^{E1} but not for r^O, since this parameter was not as well estimated for the original model as it was for the base case model.

The sub-committee identified four sensitivity runs arising from the execution of multiple model runs, both intersessionally and at this meeting, namely:

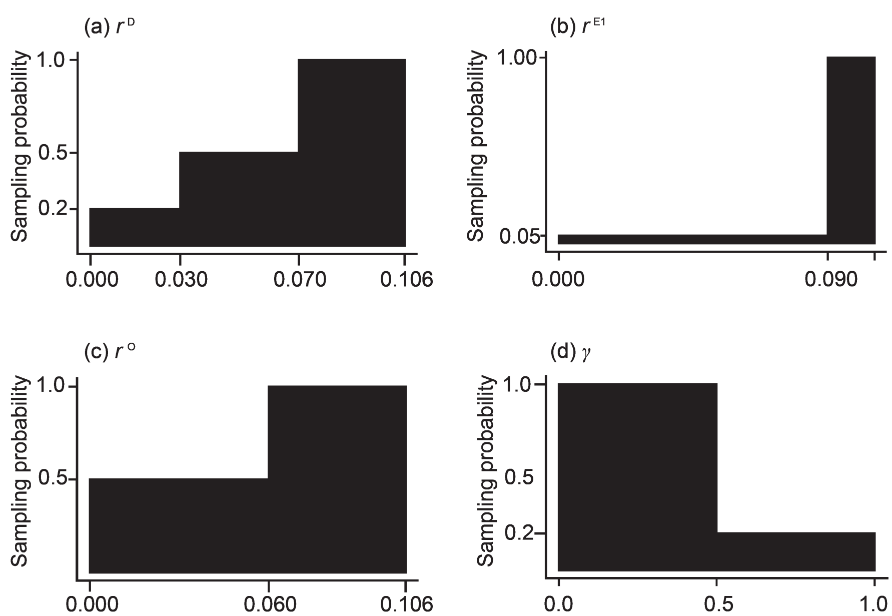

Fig. 3. Importance functions used when sampling the r^D, r^{E1}, r^O and γ parameters. The horizontal axis shows the step values at which the importance function increases, and the vertical axis shows the probability of accepting a sample from a particular range. Note that that the importance functions for r^D and r^{E1} were implemented for both the base case model and the original model. Importance functions for r^O and γ were implemented for the base case model only.

Table 1

Posterior median values of key model parameters are given with their 90% probability intervals for the base case model, the sensitivity runs as described in the text, and the original three-stock model.

		r		K				N_{min}		N_{min}/K		N_{2012}		N_{2012}/K	
BSD	Base case	0.090	[0.053; 0.104]	21,686	[19,016; 29,383]			824	[461; 3,685]	0.039	[0.023; 0.128]	19,264	[17,553; 24,012]	0.904	[0.739; 0.984]
	Sen1(i): 60°E-100°W	0.092	[0.054; 0.104]	21,649	[19,064; 29,150]			782	[460; 3,410]	0.038	[0.021; 0.118]	19,334	[17,522; 24,241]	0.906	[0.748; 0.986]
	Sen1(ii): 80°E-120°W	0.092	[0.053; 0.103]	21,204	[18,858; 28,981]			823	[469; 3,446]	0.039	[0.022; 0.126]	19,056	[17,291; 24,109]	0.914	[0.714; 0.989]
	Sen1(iii): 50% margin	0.092	[0.053; 0.104]	21,269	[18,947; 29,349]			793	[465; 3,598]	0.037	[0.022; 0.127]	19,196	[17,408; 24,194]	0.91	[0.711; 0.985]
	Sen2(i): U[18,40]	0.085	[0.035; 0.100]	22,571	[19,507; 37,481]			1,361	[663; 9,265]	0.060	[0.031; 0.232]	21,173	[19,070; 28,005]	0.944	[0.729; 0.993]
	Sen2(ii): U[20,40]	0.068	[0.034; 0.097]	26,156	[21,639; 39,684]			2,928	[960; 13,756]	0.109	[0.044; 0.359]	23,878	[21,051; 34,852]	0.952	[0.692; 0.999]
	Sen2(iii): U[15,30]	0.092	[0.053; 0.104]	21,587	[19,328; 28,909]			771	[459; 3,353]	0.037	[0.022; 0.114]	19,389	[17,438; 23,163]	0.902	[0.724; 0.983]
	Sen3: NZ to BSO	0.090	[0.053; 0.104]	21,911	[18,840; 30,511]			796	[429; 4,234]	0.035	[0.020; 0.133]	19,283	[17,571; 24,363]	0.901	[0.750; 0.981]
	Sen4: Forestell	0.088	[0.053; 0.102]	21,998	[19,677; 29,655]			784	[455; 3,432]	0.036	[0.021; 0.116]	19,252	[17,915; 23,680]	0.885	[0.789; 0.980]
	Original model	0.071	[0.032; 0.099]	23,658	[18,381; 40,297]			1,921	[579; 12,171]	0.065	[0.028; 0.364]	19,849	[17,483; 32,648]	0.889	[0.652; 0.998]
BSE1	Base case	0.105	[0.103; 0.106]	26,133	[21,605; 29,033]	0.068	[0.007; 0.190]	237	[203; 272]	0.009	[0.008; 0.011]	16,366	[14,674; 18,034]	0.634	[0.561; 0.729]
	Sen1(i): 60°E-100°W	0.105	[0.103; 0.106]	26,316	[21,592; 29,208]	0.067	[0.006; 0.201]	237	[203; 273]	0.009	[0.008; 0.011]	16,292	[14,593; 18,197]	0.631	[0.555; 0.724]
	Sen1(ii): 80°E-120°W	0.105	[0.103; 0.106]	26,334	[21,904; 29,002]	0.060	[0.005; 0.178]	236	[202; 272]	0.009	[0.008; 0.011]	16,283	[14,751; 18,249]	0.633	[0.559; 0.731]
	Sen1(iii): 50% margin	0.105	[0.103; 0.106]	26,227	[21,712; 29,117]	0.063	[0.005; 0.195]	235	[203; 272]	0.009	[0.008; 0.011]	16,288	[14,656; 18,139]	0.631	[0.558; 0.727]
	Sen2(i): U[18,40]	0.105	[0.103; 0.106]	26,410	[21,782; 29,045]	0.040	[0.004; 0.169]	236	[203; 272]	0.009	[0.008; 0.011]	16,246	[14,657; 18,193]	0.621	[0.557; 0.730]
	Sen2(ii): U[20,40]	0.105	[0.103; 0.106]	26,379	[21,607; 29,065]	0.032	[0.004; 0.167]	233	[203; 273]	0.009	[0.008; 0.011]	16,043	[14,777; 17,953]	0.614	[0.556; 0.730]
	Sen2(iii): U[15,30]	0.105	[0.103; 0.106]	26,439	[21,942; 29,140]	0.063	[0.005; 0.195]	236	[204; 273]	0.009	[0.008; 0.011]	16,369	[14,822; 18,220]	0.631	[0.560; 0.725]
	Sen3: NZ to BSO	0.106	[0.103; 0.106]	23,775	[20,620; 26,241]	0.060	[0.002; 0.169]	235	[208; 277]	0.010	[0.008; 0.013]	15,954	[14,425; 17,728]	0.676	[0.599; 0.764]
	Sen4: Forestell	0.106	[0.104; 0.106]	26,450	[22,813; 28,411]	0.036	[0.010; 0.154]	210	[200; 221]	0.008	[0.007; 0.009]	15,183	[14,472; 15,845]	0.573	[0.538; 0.647]
	Original model	0.105	[0.102; 0.106]	27,658	[22,916; 30,655]	-		238	[198,285]	0.009	[0.006,0.011]	16,599	[14,582; 18,505]	0.613	[0.476; 0.722]
BSO	Base case	0.091	[0.071; 0.101]	14,115	[10,198; 19,651]			132	[103; 250]	0.010	[0.007; 0.014]	5,072	[4,456; 6,040]	0.371	[0.238; 0.535]
	Sen1(i): 60°E-100°W	0.092	[0.072; 0.101]	14,089	[10,090; 20,015]			130	[103; 237]	0.010	[0.006; 0.014]	5,046	[4,544; 6,013]	0.377	[0.238; 0.535]
	Sen1(ii): 80°E-120°W	0.092	[0.070; 0.100]	13,930	[10,006; 18,975]			131	[102; 256]	0.011	[0.007; 0.015]	5,031	[4,528; 5,876]	0.381	[0.245; 0.535]
	Sen1(iii): 50% margin	0.092	[0.072; 0.101]	14,076	[9,982; 19,721]			132	[102; 239]	0.010	[0.007; 0.014]	5,047	[4,564; 5,942]	0.377	[0.240; 0.530]
	Sen2(i): U[18,40]	0.091	[0.070; 0.100]	13,099	[10,098; 19,473]			134	[103; 256]	0.011	[0.007; 0.014]	5,041	[4,522; 5,809]	0.378	[0.239; 0.537]
	Sen2(ii): U[20,40]	0.092	[0.070; 0.101]	12,989	[10,095; 19,009]			135	[102; 253]	0.011	[0.007; 0.015]	5,043	[4,500; 5,900]	0.378	[0.243; 0.538]
	Sen2(iii): U[15,30]	0.092	[0.072; 0.101]	13,944	[10,084; 19,295]			133	[102; 246]	0.010	[0.007; 0.014]	5,054	[4,521; 5,882]	0.379	[0.244; 0.533]
	Sen3: NZ to BSO	0.094	[0.074; 0.101]	16,418	[12,925; 20,460]			121	[101; 213]	0.008	[0.006; 0.012]	5,131	[4,163; 6,117]	0.321	[0.237; 0.436]
	Sen4: Forestell	0.093	[0.081; 0.100]	12,939	[10,759; 17,727]			130	[103; 183]	0.010	[0.007; 0.011]	4,945	[4,787; 5,859]	0.379	[0.273; 0.509]
	Original model	0.071	[0.014; 0.097]	15,094	[10,732; 23,973]			249	[113; 1,760]	0.021	[0.009; 0.085]	4,481	[2,983; 5,578]	0.298	[0.130; 0.505]

Sensitivity 1: Shifting of the Antarctic catch boundaries: ((i) 100% of catches between 60°E-100°W; (ii) 100% of catches between 80°E-120°W; and (iii) 50% catches from margin areas 60°-80°E and 120-100°W). Diagrams of catch boundaries are given under Item 3.1.2.3.

Sensitivity 2: Alternative bounds for the log of the BSD absolute abundance estimate: ((i) U[ln18,000,ln40,000]); (ii) U[ln20,000,ln40,000]; and (iii) U[ln15,000,ln30,000]).

Sensitivity 3: Allocate all New Zealand catches to BSO.

Sensitivity 4: Fit the model to the BSE1 Forestell *et al.* (2011) mark-recapture data instead of the Noad *et al.* (2011) relative abundance series.

RESULTS

Posterior median values for key model parameters are given in Table 1 for the base case model and for the specified sensitivity runs as have been provided for previous assessments. Fig. 6 provides comparisons of the median population trajectories of the sensitivity runs with those for the base case model run.

Fig. 7 shows the BSD median population trajectories with fits to the relative abundances series ((Bannister and Hedley, 2001; Hedley *et al.*, 2011) for the model fit and Chittleborough (1965 as a consistency check for the base case and the sensitivity runs. Similar plots have not been provided for BSE1 and BSO, as the results from the various runs were not qualitatively different.

Fig. 7 shows the posterior distributions for the estimated parameters for the base case model and each of the sensitivity runs.

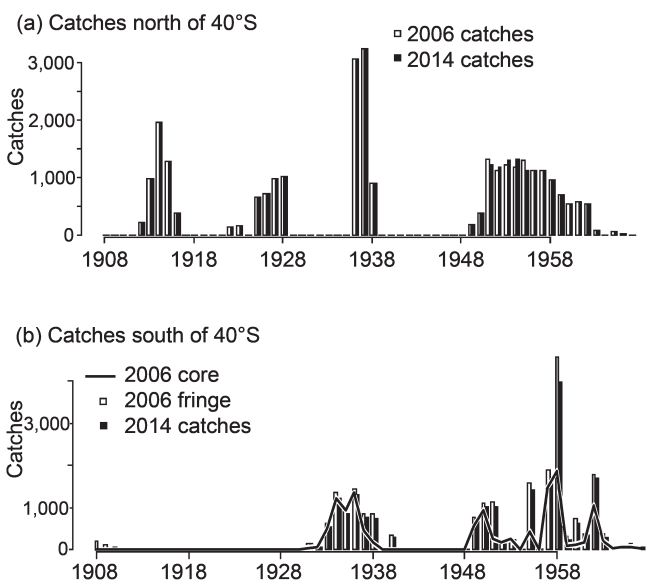

Fig. 4. Comparisons of the catches allocated to BSD in the 2006 assessment with those from the 2014 assessment. Note that the model allocates the historic feeding ground catches from 70°E-130°E to BSD and BSE1 in proportion to the relative model-predicted population sizes. The catches for the 2014 assessment in Fig. 4(b) are therefore the median feeding ground catches that are allocated to BSD in the model.

COMPARISON WITH PREVIOUS BSD ASSESSMENT RESULTS

An assessment of BSD was completed in 2006 (IWC, 2007). At the time, the sub-committee agreed that the assessment modelling results should be considered preliminary and should be re-evaluated in the future. This reassessment would require clarification of stock structure of Oceania and the Pacific Island populations and the extent of mixing at high latitudes, as catch allocation would perhaps be influenced by mixing with BSE. The sub-committee noted at the time that the population had made a substantial increase since protection.

The three-stock models run in the 2014 assessment addresses the concerns expressed above as they allow for mixing of neighbouring breeding stocks in the Antarctic feeding areas. Direct comparisons between these results and those from 2006 should be viewed with caution as there were some differences in model inputs and assumptions. The inputs of the 2006 model were agreed on in the Hobart Workshop (IWC, 2011) and included a catch allocation of 80°E-100°E (Core) and 50°E-130°E (Fringe); an absolute abundance estimate (Paxton *et al.*, 2006); and population trend information, i.e. the reference case (IWC, 1996) series from five breeding ground surveys for the period 1982 to 1994; JARPA (Matsuoka *et al.*, 2006); IDCR (Branch, 2011); and Chittleborough (1965) relative abundance series. During the Hobart Workshop, it was agreed that BSD is most closely connected to Area IV, but that there is potential mixing with Areas III and V (IWC, 2011), item 3.9, Stock D). On the basis of Discovery mark data, the catch allocation areas for BSD were defined as above. The bulk of the catches came from feeding areas and there were nearly twice as many in the Fringe as the Core area (Johnston and Butterworth, 2006).

Despite these differences in input assumptions the results of the 2006 Fringe model (Table 2, left) are similar to the current base case assessment results for BSD (Table 2,

Table 2

Selected BSD model parameter estimates for IWC (2007) (left) and for the 2014 assessment (right). Posterior medians with 5th and 95th percentiles (in brackets) are reported.

	Selected BSD model parameter estimates. Posterior medians with the 5th and 95th percentiles (in brackets) are reported.		2014 base case assessment	
	Reference case			
Catch history:	**Fringe:**	**Core:**		
***r* prior:**	**r~U[0; 0.106]**	**r~U[0; 0.106]**		
Recent abundance:	**N=10,032; CV=0.11**	**N=10,032; CV=0.11**		
Trend information	**IWC (1996)**	**IWC (1996)**		
r	0.091 [0.046; 0.105]	0.090 [0.044; 0.105]	0.090	[0.053; 0.104]
K	22,690 [21,152; 29,892]	17,730 [16,380; 24,800]	21,686	[19,016; 29,383]
N_{min}	721 [447; 2,189]	767 [470; 2,493]	824	[461; 3,685]
N_{2006}	15,729 [12,496; 17,828]	14,311 [12,227; 15,650]	15,986	[13,785; 21,700]
N_{min}/K	0.032 [0.021; 0.073]	0.043 [0.028; 0.101]	0.039	[0.023; 0.128]
N_{2006}/K	0.689 [0.420; 0.812]	0.804 [0.503; 0.907]	0.735	[0.580; 0.939]
N_{2020}/K	0.978 [0.686; 0.994]	0.990 [0.762; 0.998]	0.984	[0.883; 0.998]
N_{2040}/K	1.000 [0.942; 1.000]	1.000 [0.961; 1.000]	1.000	[0.991; 1.000]

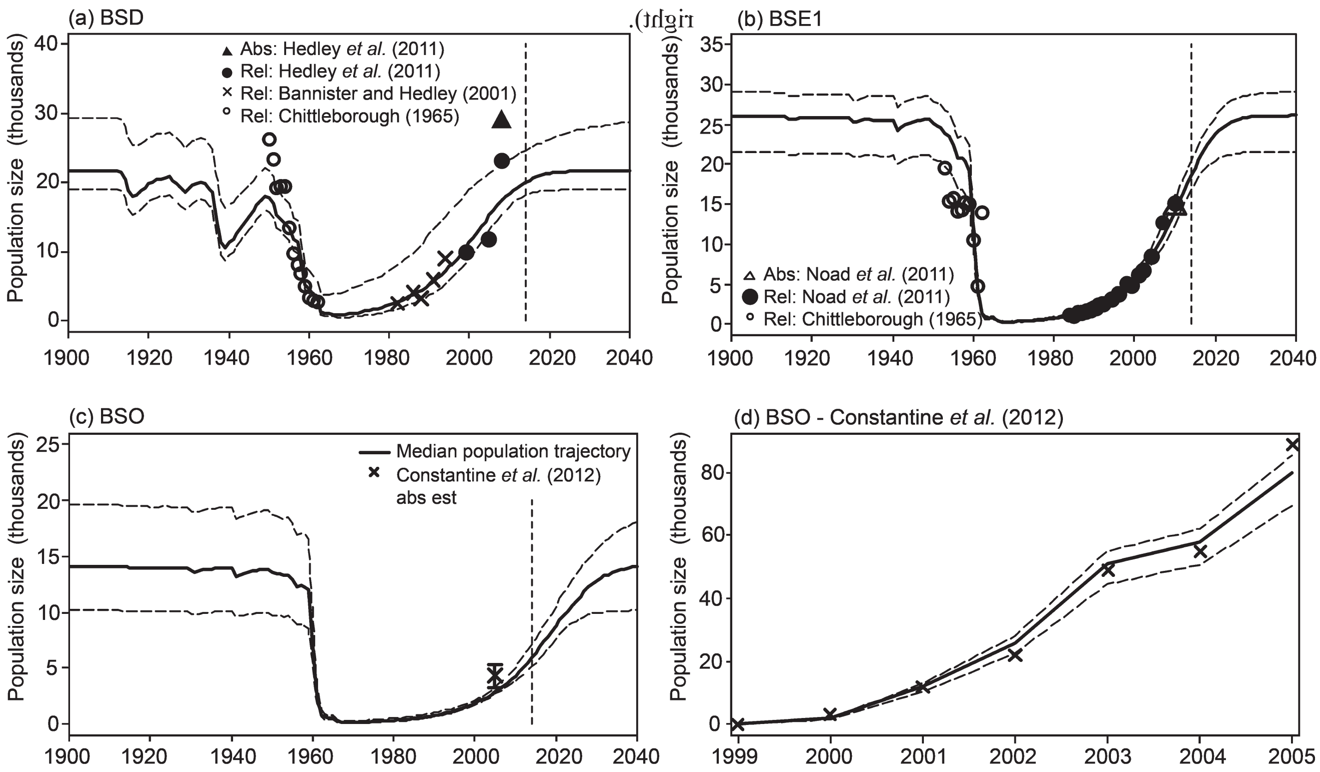

Fig. 5. (a)-(c) show the median population trajectories for the base case three-stock model. 90% probability envelopes are indicated by the dashed lines. The model is fit to the Bannister and Hedley (2001) and the Hedley *et al.* (2011) relative abundance series for BSD (fits shown in Fig. 5(a)); the Noad *et al.* (2011) absolute and relative abundance series for BSE1 (fits shown in Fig.5(b)), and to the Constantine *et al.* (2012) mark-recapture data for BSO (Fig.5(c)). In Fig.5(c), the cumulative observed re-sightings are marked by X's. Fits to the Hedley *et al.* (2011) absolute abundance estimate (Fig.5(a)); the Chittleborough (1965) relative abundance series (Fig.5(a) and 5(b)); and the Constantine *et al.* (2012) absolute abundance estimate (Fig.5(c)) are shown as consistency checks.

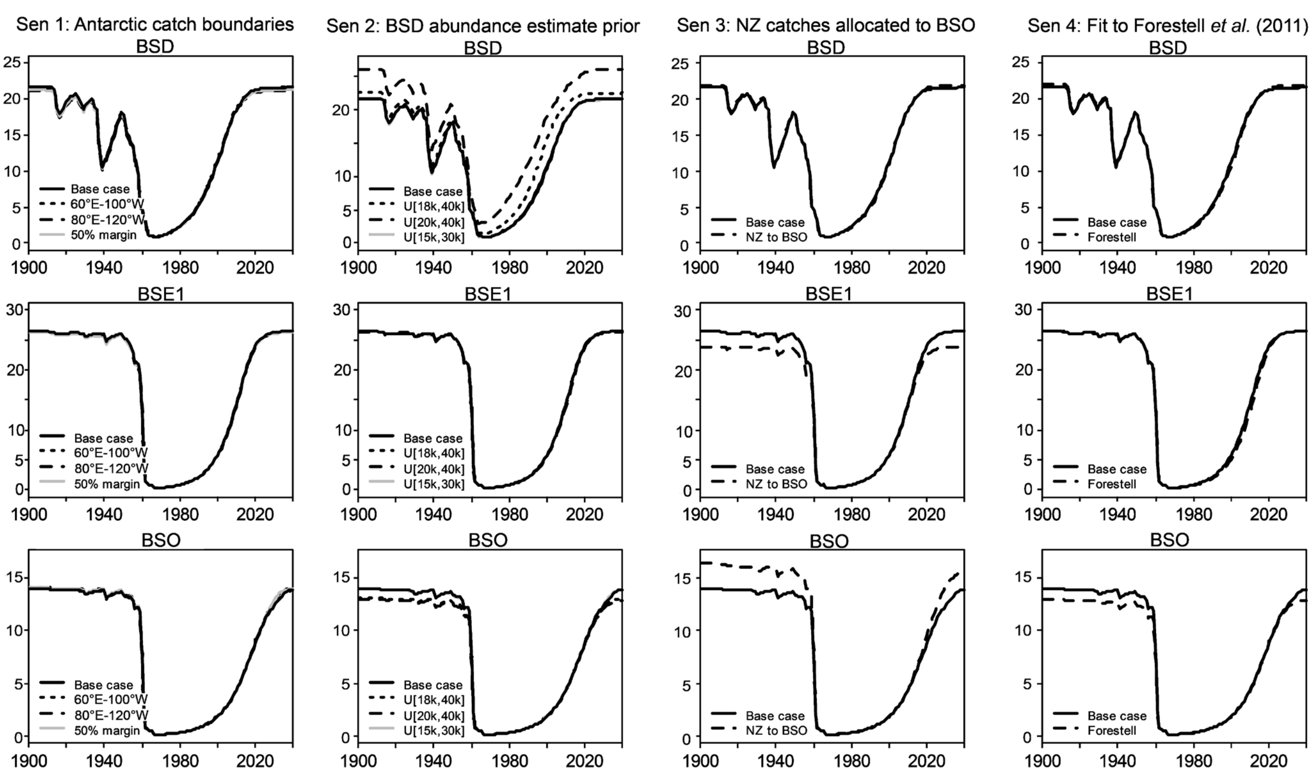

Fig. 6. Median population 'trajectories' for each of the four sensitivity runs (note that strictly these are not actual trajectories, but juxtaposition of successive values form posterior probability distributions for each year). For each plot, the solid line corresponds to the base case run.

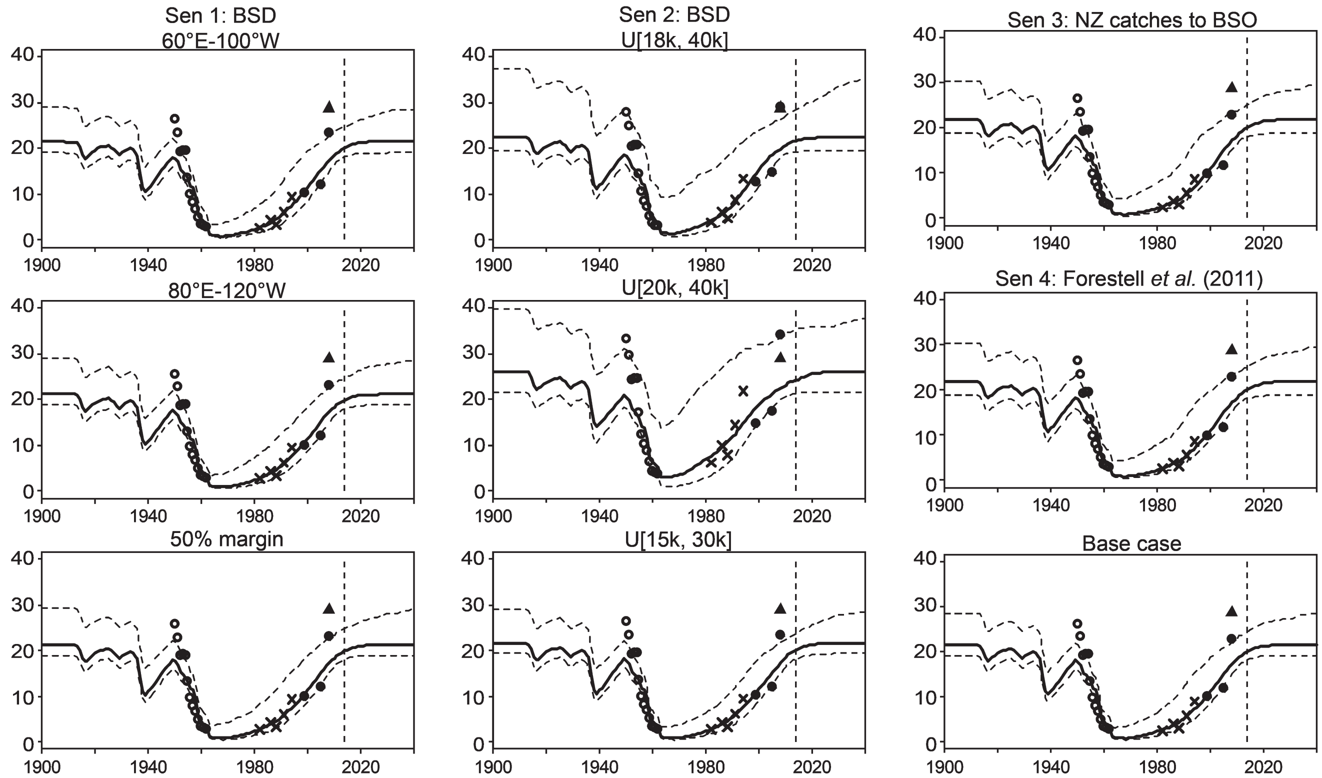

Fig. 7: BSD median population trajectories, 90% probability envelopes (indicated by dashed lines), and fits to the relative abundance series for the three sensitivity runs. Plots show fits to the Chittleborough (1965) relative abundance series (open circles), the Bannister and Hedley (2001) relative 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 and Hedley (2001) relative abundance series. The Chittleborough (1965) relative abundance series and Hedley *et al.* (2011) absolute abundance estimate are shown as consistency checks.

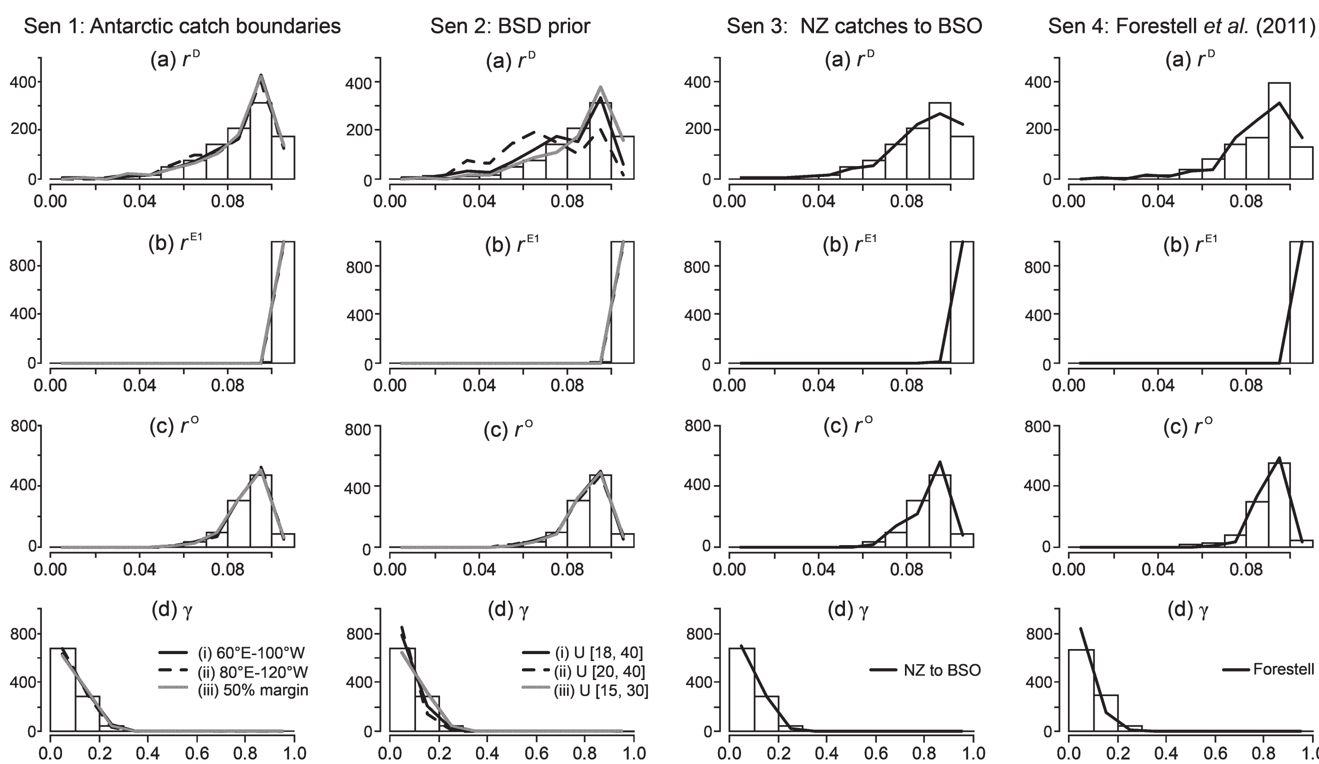

Fig. 8: Posterior distributions. The white bars give the posterior distributions for the base case, and the lines for the sensitivity runs as described in the figure legends. In all cases the prior distributions were uniform, but note truncation effects for the final bar in the r plots as that bar spans [0.10,0.11], but the prior extends only to r=0.106.

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