Alternative hypotheses of two mixing stocks of South African sardine: Initial testing

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Background

A new assessment of sardine based on data from 1984 to 2014 is planned to commence in a few months' time. This assessment will eventually form the operating model which will be used to project the sardine population forward in time under alternative future catch scenarios – i.e. it will be used in the development of the next OMP to likely be finalised in 2016.

In preparation for this assessment, some initial potential alternative two mixing stock hypotheses are considered using the previous assessment based on data from 1984 to 2011 (de Moor and Butterworth In Review) which has been used in the development of OMP-14. These tests would hopefully highlight any hypotheses that could have a substantial influence on model results and those which might not, and thus aid in prioritisation of future research.

This document is a first stage of this process, firstly outlining the alternative hypotheses currently considered plausible, and then refitting the previous assessment at the joint posterior mode for some of these hypotheses.

Current Two Stock Hypothesis

The two stock hypothesis as agreed for use during the previous assessment assumes that sardine consist of a west stock distributed to the west of Cape Agulhas and a south stock distributed to the south-east of Cape Agulhas. The November survey is assumed to survey only west stock fish west of Cape Agulhas and only south stock fish south-east of Cape Agulhas. The recruit survey is assumed to survey only west stock fish west of Cape Infanta (although east of Cape Agulhas, this was chosen as the traditional boundary for the time series of single stock recruitment) and only south stock fish south-east of Cape Infanta. The only mixing between the sardine is assumed to be the movement of an annually-varying proportion of recruits from the west to the south stock in the November in which they become 1 year olds.

Alternative Two Stock Hypotheses

Alternative A (Effective Spawning Biomasses)

A small proportion (<20%) of eggs spawned on the south coast have been shown to be successfully transported in model simulations to a pre-defined west coast nursery area (Miller et al. 2006, Coetzee 2014) and an even smaller proportion of eggs spawned on the west coast have also been shown to be successfully transported to a pre-defined

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south coast nursery area. These nursery areas may not be ideally defined given current knowledge, but the historical nature of the Individual Based Model simulation from which these results are drawn renders changes to nursery area definitions impossible, at least in the short term. This alternative hypothesis thus assumes that a portion of the west/south spawning stock biomass (SSB) forms part of the "effective spawning biomass" of the other stock. The recruitment to a stock is assumed to stem from this "effective spawning biomass". Assuming the percentages of eggs shown to move by Coetzee (2014) is a reliable indication of the percentage of spawning biomass that contributes to recruitment of the "other" stock, the hypotheses considered are as follows:

Baseline: 0% of south SSB contributes to effective west SSB

                0% of west SSB contributes to effective south SSB

Alt A-1:   **10%** of south SSB contributes to effective west SSB

                0% of west SSB contributes to effective south SSB

                (an intermediary option)

Alt A-2:   **18%** of south SSB and 100% of west SSB contributes to effective west SSB

                0% of west SSB and **82%** of south SSB contributes to effective south SSB

                (equalling the percentage of eggs from Coetzee 2014, ignoring the proportions of eggs 'lost to the system', but assuming only south SSB benefits west stock recruitment)

Alt A-3:   **18%** of south SSB and **98%** of west SSB contributes to effective west SSB

                2% of west SSB and **82%** of south SSB contributes to effective south SSB

                (equalling the percentage of eggs from Coetzee 2014, ignoring the proportion of eggs 'lost to the system')

Alt A-4:   **10%** of south SSB and **29%** of west SSB contributes to effective west SSB

                0.5% of west SSB and **46%** of south SSB contributes to effective south SSB

                (equalling the percentage of eggs from Coetzee 2014, assuming the proportion of eggs 'lost to the system' equates to unproductive spawning biomass)

Alt A-5:   **13%** of south SSB and **29%** of west SSB contributes to effective west SSB

                0.5% of west SSB and **59%** of south SSB contributes to effective south SSB

                (equalling the percentage of eggs from Coetzee 2014, assuming the proportion of eggs 'lost to the system' equates to unproductive spawning biomass; and that the proportion of eggs 'lost to the system' reported by Coetzee 2014 is reasonable for the west stock, but is overestimated by a factor ot two for the south stock given that the modelled south coast nursery area (from Cape Infanta to Plettenberg Bay) is smaller than it is thought to be in reality (from Cape Infanta to Algoa Bay)[1])

The changes to the model (de Moor and Butterworth In Review) are as follows:

Given the spawning stock biomass:

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[1] From Alt A-4, 10% of eggs spawned on the south coast were transported to the west coast, 46% were retained on the south coast and 44% lost to the system. Halving the amount lost to 22% and renormalizing results in 13% of eggs spawned on the south coast being transported to the west coast, 59% retained on the south coast and 28% lost to the system.

$$SSB_{j,y}^{S} = \sum_{a=2}^{5+} N_{j,y,a}^{S} w_{j,y,a}^{S} \qquad\qquad y = y_1,\ldots,y_n \qquad\qquad (1)$$

the effective spawning stock biomass is calculated as:

$$SSB_{1,y}^{eff\ S} = SSB_{w\_w} \times SSB_{1,y}^{S} + SSB_{s\_w} \times SSB_{2,y}^{S}$$

$$SSB_{1,y}^{eff\ S} = SSB_{w\_s} \times SSB_{1,y}^{S} + SSB_{s\_s} \times SSB_{2,y}^{S}$$

and the recruitment is related to the effective rather than actual spawning stock biomass as follows:

$$N_{j,y,0}^{S} = f\left(SSB_{j,y}^{eff\ S}\right) e^{\varepsilon_{j,y}^{S}} \qquad\qquad y = y_1,\ldots,y_n \qquad\qquad (2)$$

Here:

$N_{j,y,a}^{S}$ is the model predicted number (in billions) of sardine of age a at the beginning of November in year y of stock j;

$w_{j,y,a}^{S}$ is the mean mass (in grams) of sardine of age a of stock j sampled during the November survey of year y;

SSB_{w_w} is the proportion of the west SSB contributing to the effective west SSB;

SSB_{w_s} is the proportion of the west SSB contributing to the effective south SSB;

SSB_{s_w} is the proportion of the south SSB contributing to the effective west SSB;

SSB_{s_s} is the proportion of the south SSB contributing to the effective south SSB;

$f(\ )$ denotes the assumed stock-recruitment relationship; and

$\varepsilon_{j,y}^{S}$ is the annual lognormal deviation of sardine recruitment.

Alternative B (Varied Recruit Distributions)

de Moor and Butterworth (2013) showed some relationship between the proportion of recruits moving from the west stock to the south stock and the 1+ biomass of the south stock in the previous November. This may be a reflection of some south stock recruits being surveyed west of Cape Infanta in May/June prior to completing their return migration to the south stock (i.e. natal homing). In this hypothesis, the recruits surveyed west of Cape Infanta thus consist of west stock recruits and a portion of south stock recruits. For simplicity as an initial test, it is assumed that these south stock recruits surveyed west of Cape Infanta are not caught west of Cape Agulhas. There is no prior information to inform this proportion and thus a number of alternatives are tested:

Baseline: 0% of south stock recruits distributed west of Cape Infanta at the time of the survey

Alt B-1:   **10%** of south stock recruits distributed west of Cape Infanta at the time of the survey

Alt B-2:   **20%** of south stock recruits distributed west of Cape Infanta at the time of the survey

Alt B-3:   **50%** of south stock recruits distributed west of Cape Infanta at the time of the survey

The changes to the model (de Moor and Butterworth In Review) are as follows:

$$N'^{S}_{1,y,r} = N^{S}_{1,y,r} + obs \times N^{S}_{2,y,r}$$

$$N'^{S}_{2,y,r} = (1 - obs) \times N^{S}_{2,y,r} \qquad\qquad\qquad y = y_1, \ldots, y_n \qquad\qquad (3)$$

and $N'^{S}_{j,y,r}$ replaces $N^{S}_{j,y,r}$ in the likelihood. Here:

$N^{S}_{j,y,r}$ is the model predicted number (in billions) of juvenile sardine of stock j at the time of the recruit survey in year *y*; and

obs   is the time-invariant proportion of south stock recruits surveyed west of Cape Infanta.

Alternative C (Varied Adult Distributions)

van der Lingen and Hendricks (2014) and van der Lingen et al. (In Press) have shown differences in the prevalence, mean infection intensity and mean abundance of a parasite (considered to be of the genus *Cardiocephaloides*) between sardine caught west and east of Cape Agulhas. Assuming the infection area is endemic to the west coast of South Africa, an increase in parasite infection prevalence and intensity with length for sardine east of Cape Agulhas might not be sufficiently explained by allowing only recruits to migrate from the west to the south stock.

This could be an indication that a portion of the south stock is found distributed to the west of Cape Agulhas for part of the year, reflecting a temporary north-westward shift in either the south or both of the south and west stocks. This idea follows from the seasonal north-south movement observed in three stocks of Pacific sardine (*Sardinops sagax*, Félix-Uraga et al. 2004). However, there is currently no information to inform the timing of this hypothesised north-west and return south-east movement of the South African sardine stocks.

The north-south movement of three groups of Pacific sardine has been linked to sea surface temperature and the strengthening/weakening of the California Current (Félix-Uraga et al. 2004). Their model showed southward movement of sardine in winter with the sardine being southernmost in spring and northward movement in summer with the sardine being northernmost in autumn. Given the different hemispheres, one might thus expect the South African sardine to move north-west in winter and spring and southwards in summer and autumn. In this hypothesis a portion of the south stock adults are assumed to be distributed west of Cape Agulhas from May to October each year, during which time they would be exposed to infection by the *Cardiocephaloides* parasite.

Alternatively, based on observations from both the November spawner and May/June recruit surveys, of higher concentrations of sardine on the south coast prior to the start of the sardine run and of higher sardine catches off the south coast during winter[2] would require south stock sardine to be distributed off the south coast during winter. In this case a portion of the south stock adults are assumed to be distributed west of Cape Agulhas from February to April and from August to October.

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[2] Observed off Mossel Bay, but not off Port Elizabeth (van der Lingen and van der Westhuizen 2014), although this may be further complicated by the possible presence of an "east" stock (Fréon et al. 2010).

Directed catch and bycatch with round herring taken west of Cape Agulhas is assumed to be taken from the west and south stocks in proportion to their numbers found west of Cape Agulhas in each quarter of the year. It is assumed that only the south stock adults move west of Cape Agulhas and thus the bycatch of juvenile sardine either with anchovy or with directed sardine is assumed to consist of only west stock juvenile sardine. These hypotheses assume all the south stock biomass is distributed and thus surveyed south-east of Cape Agulhas during the November hydro-acoustic survey. Although distributed west of Cape Agulhas at some point during the year, all the south stock fish are assumed to grow according to the same growth curve, which is modelled to differ from that of west stock fish. The alternatives tested are as follows:

<u>Baseline</u>:   0% of south stock fish are found distributed west of Cape Agulhas during the year

i.e. catch west of Cape Agulhas is taken from west stock and 0% of south stock fish

<u>C-1</u>:   **20%** of south stock fish are found distributed west of Cape Agulhas during **May to October**

i.e. catch west of Cape Agulhas is taken from west stock and **20%** of south stock fish in **May to October**

<u>C-2</u>:   **40%** of south stock fish are found distributed west of Cape Agulhas during **May to October**

i.e. catch west of Cape Agulhas is taken from west stock and **40%** of south stock fish in **May to October**

<u>C-3</u>:   **20%** of south stock fish are found distributed west of Cape Agulhas during **February to April and August to October**

i.e. catch west of Cape Agulhas is taken from west stock and **20%** of south stock fish in **February to April and August to October**

<u>C-4</u>:   **40%** of south stock fish are found distributed west of Cape Agulhas during **February to April and August to October**

i.e. catch west of Cape Agulhas is taken from west stock and **40%** of south stock fish in **February to April and August to October**

The changes to the model (de Moor and Butterworth In Review) are as follows:

i) Fishing mortality and commercial selectivity-at-length is assumed to be coast- (c) rather than stock- (j) specific:

The fished proportion of the available biomass from the directed and redeye bycatch fisheries is estimated by:

$$F_{c,y,1} = \frac{\sum\limits_{fleet=1}^{2} \sum\limits_{m=11}^{12} \sum\limits_{l>=6cm} C_{c,y-1,m,l}^{RLF,fleet} + \sum\limits_{fleet=1}^{2} \sum\limits_{l>=6cm} C_{c,y,1,l}^{RLF,fleet}}{\sum\limits_{l>=6cm} S_{c,y,l} \sum\limits_{j} dist_{j,c,1} \left\{ \sum\limits_{a=0}^{5+} A_{j,1,a,l}^{com} \left(N_{j,y-1,a}^{S} e^{-M_a^S/8} - C_{j,y,1,a}^{bycatch} \right) \right\}}$$

$$F_{c,y,2} = \frac{\sum\limits_{fleet=1}^{2} \sum\limits_{m=2}^{4} \sum\limits_{l>=6cm} C_{c,y,m,l}^{RLF,fleet}}{\sum\limits_{l\geq6cm} S_{c,y,l} \sum\limits_{j} dist_{j,c,2} \left\{ \sum\limits_{a=0}^{5+} A_{j,2,a,l}^{com} \left(\left(N_{j,y-1,a}^{S} e^{-M_a^S/8} - C_{j,y,1,a}^{S} \right) e^{-M_a^S/4} - C_{j,y,2,a}^{bycatch} \right) \right\}}$$

$$F_{c,y,3} = \frac{\sum\limits_{fleet=1}^{2} \sum\limits_{m=5}^{7} \sum\limits_{l>=6cm} C_{c,y,m,l}^{RLF,fleet}}{\sum\limits_{l\geq 6cm} S_{c,y,l} \sum\limits_{j} dist_{j,c} \left\{ \sum\limits_{a=0}^{5+} A_{j,3,a,l}^{com} \left(\left(\left(N_{j,y-1,a}^{S} e^{-M_a^S/8} - C_{j,y,1,a}^{S} \right) e^{-M_a^S/4} - C_{j,y,2,a}^{S} \right) e^{-M_a^S/4} - C_{j,y,3,a}^{bycatch} \right) \right\}}$$

$$F_{c,y,4} = \frac{\sum\limits_{fleet=1}^{2} \sum\limits_{m=8}^{10} \sum\limits_{l>=6cm} C_{c,y,m,l}^{RLF,fleet}}{\sum\limits_{l\geq 6cm} S_{c,y,l} \sum\limits_{j} dist_{j,c} \sum\limits_{a=0}^{5+} A_{j,4,a,l}^{com} \left(\left(\left(\left(N_{j,y-1,a}^{S} e^{-M_a^S/8} - C_{j,y,1,a}^{S} \right) e^{-M_a^S/4} - C_{j,y,2,a}^{S} \right) e^{-M_a^S/4} - C_{j,y,3,a}^{S} \right) e^{-M_a^S/4} - C_{j,y,4,a}^{bycatch} \right)} \quad (4)$$

The commercial catch-at-age from the directed and redeye bycatch fisheries is:

$$C_{j,y,1,a}^{dir} = \sum_{c} \sum_{l\geq 6cm} dist_{j,c,1} \left(N_{j,y-1,a}^{S} e^{-M_a^S/8} - C_{j,y,1,a}^{bycatch} \right) A_{j,1,a,l}^{com} S_{c,y,l} F_{c,y,1}$$

$$C_{j,y,2,a}^{dir} = \sum_{c} \sum_{l\geq 6cm} dist_{j,c,2} \left(\left(N_{j,y-1,a}^{S} e^{-M_a^S/8} - C_{j,y,1,a}^{S} \right) e^{-M_a^S/4} - C_{j,y,2,a}^{bycatch} \right) A_{j,2,a,l}^{com} S_{c,y,l} F_{c,y,2}$$

$$C_{j,y,3,a}^{dir} = \sum_{c} \sum_{l\geq 6cm} dist_{j,c,3} \left(\left(\left(N_{j,y-1,a}^{S} e^{-M_a^S/8} - C_{j,y,1,a}^{S} \right) e^{-M_a^S/4} - C_{j,y,2,a}^{S} \right) e^{-M_a^S/4} - C_{j,y,3,a}^{bycatch} \right) A_{j,3,a,l}^{com} S_{c,y,l} F_{c,y,3}$$

$$C_{j,y,4,a}^{dir} = \sum_{c} \sum_{l\geq 6cm} dist_{j,c,4} \left(\left(\left(\left(N_{j,y-1,a}^{S} e^{-M_a^S/8} - C_{j,y,1,a}^{S} \right) e^{-M_a^S/4} - C_{j,y,2,a}^{S} \right) e^{-M_a^S/4} - C_{j,y,3,a}^{S} \right) e^{-M_a^S/4} - C_{j,y,4,a}^{bycatch} \right) A_{j,4,a,l}^{com} S_{c,y,l} F_{c,y,4}$$

$$y = y_1, \ldots, y_n, \ l = 3.5cm, \ldots, 23cm \quad (5)$$

The commercial catch-at-length from the directed and redeye bycatch fisheries is:

$$C_{j,y,1,l}^{dir} = \sum_{c} \sum_{a=0}^{5+} dist_{j,c,1} \left(N_{j,y-1,a}^{S} e^{-M_a^S/8} - C_{j,y,1,a}^{bycatch} \right) A_{j,1,a,l}^{com} S_{c,y,l} F_{c,y,1}$$

$$C_{j,y,2,l}^{dir} = \sum_{c} \sum_{a=0}^{5+} dist_{j,c,2} \left(\left(N_{j,y-1,a}^{S} e^{-M_a^S/8} - C_{j,y,1,a}^{S} \right) e^{-M_a^S/4} - C_{j,y,2,a}^{bycatch} \right) A_{j,2,a,l}^{com} S_{c,y,l} F_{c,y,2}$$

$$C_{j,y,3,l}^{dir} = \sum_{c} \sum_{a=0}^{5+} dist_{j,c,3} \left(\left(\left(N_{j,y-1,a}^{S} e^{-M_a^S/8} - C_{j,y,1,a}^{S} \right) e^{-M_a^S/4} - C_{j,y,2,a}^{S} \right) e^{-M_a^S/4} - C_{j,y,3,a}^{bycatch} \right) A_{j,3,a,l}^{com} S_{c,y,l} F_{c,y,3}$$

$$C_{j,y,4,l}^{dir} = \sum_{c} \sum_{a=0}^{5+} dist_{j,c,4} \left(\left(\left(\left(N_{j,y-1,a}^{S} e^{-M_a^S/8} - C_{j,y,1,a}^{S} \right) e^{-M_a^S/4} - C_{j,y,2,a}^{S} \right) e^{-M_a^S/4} - C_{j,y,3,a}^{S} \right) e^{-M_a^S/4} - C_{j,y,4,a}^{bycatch} \right) A_{j,4,a,l}^{com} S_{c,y,l} F_{c,y,4}$$

$$y = y_1, \ldots, y_n, \ l = 3.5cm, \ldots, 23cm \quad (5)$$

The model predicted proportion-at-length in the commercial catch from the directed and redeye bycatch fisheries is:

$$p_{c,y,q,l}^{coml,S} = \sum_{j} dist_{j,c,q} \frac{C_{j,y,q,l}^{dir}}{\sum\limits_{l} C_{j,y,q,l}^{dir}} \ ^3 \qquad\qquad y = y_1, \ldots, y_n, \ q = 1, \ldots, 4, \ l = 3.5cm, \ldots, 23cm \quad (6)$$

Here:

$N_{j,y,a}^{S}$ is the model predicted number (in billions) of sardine of age a at the beginning of November in year y of stock j;

$C_{j,y,a,q}^{S}$ is the model predicted number (in billions) of sardine of age a of stock j caught during quarter q of year y;

$C_{j,y,q,a}^{bycatch}$ is the number (in billions) of sardine of age a of stock j caught as bycatch in the anchovy fishery

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[3] See footnote 7 and the section "Fixed Parameters" for the base case hypotheses. Commercial selectivity at length is fixed = 0 for length classes <6cm, and thus the commercial proportions-at-length in length classes < 6cm in equation (A.20) are not used in fitting the model.

during quarter q of year y;

$M_{a,y}^{S}$ is the rate of natural mortality (in year^{-1}) of sardine of age a in year y;

$dist_{j,c,q}$ is the proportion of stock j found distributed on coast c in quarter q;

$S_{c,y,q,l}$ is the directed sardine and bycatch with round herring commercial selectivity-at-length l in quarter q of year y on coast c;

$S_{c,y,q,a}$ is the directed sardine and bycatch with round herring commercial selectivity-at-age a in quarter q of year y on coast c;

$F_{c,y,q}$ is the fished proportion in quarter q of year y for a fully selected age class a on coast c, by the directed and redeye bycatch fisheries;

$C_{c,y,m,l}^{RLF,fleet}$ is the number of fish landed by *fleet* in length class l landed in month m of year y from coast c (the 'raised length frequency');

$A_{j,a,l}^{sur}$ is the proportion of sardine of age a in stock j that fall in the length group l in November; and

$A_{j,q,a,l}^{com}$ is the proportion of sardine of age a in stock j that fall in the length group l in quarter q.

Alternative D (Varied Adult Movement)

The observation that parasite infection prevalence and intensity increases with length for sardine east of Cape Agulhas (van der Lingen and Hendricks 2014, van der Lingen et al. In Press) used to develop Alternative C, could alternatively be an indication that some adult west stock sardine migrate to the south stock in addition to the recruits which are modelled to migrate in the November in which they become 1 year olds. Given the lack of data to distinguish between age-dependent movement, as an initial test, the proportion of adult fish which migrate is assumed to be the same as that of the juveniles. The alternatives tested are:

Baseline: Only west stock recruits migrate to the south stock as they turn 1 year old. The proportion migrating is estimated annually from 1994.

D-1:   West stock recruits **and 1 year olds** migrate to the south stock as they turn 1 and 2 years old, respectively. The age-independent proportion migrating is estimated annually from 1994.

D-2:   West stock sardine of **all ages** migrate to the south stock. The age-independent proportion migrating is estimated annually from 1994.

D-3:   West stock recruits **and 1 year olds** migrate to the south stock as they turn 1 and 2 years old, respectively. The proportion migrating is estimated annually from 1994, and the **proportion of 1 year olds is assumed to be half that of the recruits**.

D-4:   West stock sardine of **all ages** migrate to the south stock. The proportion migrating is estimated annually from 1994, and the **proportion of adults migrating is assumed to be half that of the recruits**.

Results

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Alternative A (Effective Spawning Biomasses)

The difference in the likelihood at the joint posterior mode between the baseline and the Alt A hypotheses is minor (Table 1), however although the AIC suggests Alt A-2, A-3, A-4 and A-5 may better fit the data, these alternatives have not converged at the joint posterior mode. Figure 1 shows the difference in the stock recruitment relationships at the joint posterior mode with a lower maximum median recruitment estimated for the west stock under Alt A-2, A-3, A-4 and A-5 and a lower biomass above which maximum west stock recruitment is achieved for A-4 and A-5. The estimated effective spawner biomass in November 2011 is thus closer to (in some cases lower than) the maximum median recruitment on the stock recruit curve than under the baseline hypothesis. Figure 2 shows the difference in the actual and effective SSBs, with the effective west SSB increasing from the actual SSB in the early 2000s under A-1, A-2 and A-3 when the south stock SSB peaked. As expected, the effective SSB is much lower than the actual SSB under A-4 and A-5. The annual proportion of west stock recruits modelled to migrate to the south stock increases slightly during the 1999-2008 period and decreases slightly from 2001-2004 (Figure 3).

Alternative B (Varied Recruit Distributions)

There is little difference between the baseline and Alt B-1 and B-2, while Alt B-3 results in a poorer fit to the data (Table 1, Figures 4 and 5).

Alternative C (Varied Adult Distributions)

Results for Alternative C are not yet available.

Alternative D (Varied Adult Movement)

There is little difference in results if the same proportion of both recruits and age 1 west stock sardine are assumed to move to the south stock when they turn 1 and 2, respectively (Table 1, Figures 6 and 7). However, the model estimated proportions moving are lower under Alt D-1 compared to the Baseline to account for the additional numbers of fish moving (Figure 8). Allowing all sardine to move results in a better fit to the data, particularly the November survey estimates of south stock biomass, but these alternatives have not converged at the joint posterior mode (Table 1). The south stock spawner biomass during the peak years is estimated to be almost double that under the Baseline (Figure 7).

Discussion

Given the information collated by Coetzee (2014), Alt A-3 is preferred *a priori* to Alt A-2 and both are preferred *a priori* to Alt A-1. The proportion of eggs "lost to the system" as reported by Coetzee (2014) are likely exaggerated due to the limited spatial extent of the nursery areas in Miller et al. (2006). The exaggeration is likely minimal for the west coast where the actual nursery area extends northwards from the Orange River mouth to the Luderitz upwelling. However, the exaggeration for the south coast is likely substantial as the nursery area is thought to extend further east from Plettenberg Bay to the eastern edge of Algoa Bay. Thus the results from Alt A-3 and Alt A-4 likely

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cover the extremes possible, with Alt A-5 assuming the actual loss of south coast spawned eggs to the system is half that recorded by Miller et al. (2006). Figure 9 compares the stock recruit curves of these two likely extremes to the baseline and Alt A-5. Further sensitivities such as assuming this loss to be a quarter of that recorded by Miller et al. (2006) could be tested.

The poorer fit to the data obtained from alternative hypothesis B-3 compared to the baseline, B-1 and B-2 indicates that the majority of south stock recruits are likely surveyed east of Cape Infanta in May/June each year. It is also possible that the proportion of south stock recruits surveyed west of Cape Infanta changes each year, but there is currently insufficient data to estimate such inter-annual changes. The results at the joint posterior mode indicate these alternatives may produce similar projections to the baseline.

A variant of the alternative "B" hypotheses (*Varied Recruit Distributions*) could be to alternatively assume that a small fixed percentage of recruits annually surveyed west of Cape Infanta are south stock recruits. This alternative has not yet been tested.

Although results for the alternative "C" hypotheses (*Varied Adult Distributions*) are not yet available, as the south stock extends all the way to Algoa Bay it is most likely that if this hypothesis is true, the proportions of south stock distributed west of Cape Agulhas are low, e.g. 10, 20 or 30%. 20% and 40% have been suggested for initial testing, with the latter chosen to test the effect of an extreme.

The alternative "C" hypotheses (*Varied Adult Distributions*) assume that the differences in the parasite prevalence, mean infection intensity and mean abundance between sardine caught west and east of Cape Agulhas is due to a proportion of the south stock 1+ sardine being distributed west of Cape Agulhas for a fixed period during the year. This could, alternatively, be an indication that some south stock fish move west of Cape Agulhas for short time periods throughout the year, but that the movement of the individual schools is relatively independent of one another, such that at any point during the year a fixed proportion (of likely 10-20%) of the south stock is found to be distributed west of Cape Agulhas. It was decided first to test the alternative "C" hypotheses, as this alternative would be less extreme.

The percentages used in the alternative "D" hypotheses (*Varied Adult Movement*) have been chosen rather arbitrarily at this stage. These initial results indicate that allowing sardine of all ages to migrate from the west to the south stock may produce a better fit to the November survey data, particularly during the years of peak south stock biomass, but analyses thus far have failed to satisfactorily converge on the joint posterior mode.

It is hoped that in the next assessment, four years of parasite infection prevalence-by-length and/or parasite infection intensity-by-length data may help with the estimation of juvenile and adult movement. These data may better inform the estimation of the movement of sardine in recent years and/or may enable the estimation of the difference in the

proportion of "older" fish that move from the west to the south stock compared to the proportion of recruits that move.

Further work

MCMC chains of the alternative hypotheses which have converged to the joint posterior mode are currently being run. Once posterior distributions of the key model parameters are obtained, the operating model can be projected forward 20 years under these alternative hypotheses.

In addition, it is hoped to re-run some of these alternatives without estimating a stock-recruitment relationship within the model. Initial "short-cut" attempts at downweighting the influence of the stock-recruitment relationship by increasing the fixed variability about this relationship did not result in large differences in results nor in a positive definite Hessian in cases where this had not been achieved for the above results. Fixing the parameters of the stock recruitment curve also did not help achieve convergence to the joint posterior mode for the above cases for which this was not achieved.

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Table 1. Number of model parameters, contributions to the negative log posterior at the estimated joint posterior mode, and the difference in the model selection criteria AIC, where AIC for Baseline is -1125.84.

Alternative Hypothesis	Total parameters	$-\ln Posterior$	$-\ln L^{Nov}$	$-\ln L^{rec}$	$-\ln L^{sur\ propl\ \min}$	$-\ln L^{sur\ propl}$	$-\ln L^{com\ propl}$	$-\ln prior\left(k_{ac}^{S}\right)$	$-\ln prior\left(\varepsilon_{j,y}^{S}\right)$	ΔAIC^{4}
Base	105	684.8	47.7	53.6	507.1	5.4	54.2	-1.6	18.4	
A-1	105	685.2	47.4	54.1	507.3	5.4	53.8	-1.6	18.8	0.21
A-2	105	684.7*	46.2	53.7	507.6	5.4	53.6	-1.6	19.7	**-2.89***
A-3	105	684.6*	46.2	53.7	507.6	5.4	53.5	-1.6	19.7	**-3.08***
A-4	105	684.3*	46.4	53.6	507.8	5.3	53.2	-1.6	19.5	**-3.19***
A-5	105	684.4*	46.6	53.5	507.9	5.3	53.0	-1.6	19.6	**-3.16***
B-1	105	685.1	47.9	53.8	507.1	5.4	54.1	-1.6	18.4	0.70
B-2	105	685.6	48.1	54.0	507.1	5.4	54.1	-1.6	18.4	1.62
B-3	105	688.4	49.0	55.4	507.2	5.4	54.3	-1.6	18.6	6.85
C-1	#									
C-2	#									
C-3	#									
C-4	#									
D-1	105	684.4	47.1	53.3	506.6	5.5	54.3	-1.6	19.2	-0.71
D-2	105	648.0*	45.6	53.9	505.4	5.3	57.5	-1.7	17.9	-1.57*
D-3	105	683.8*	47.0	53.3	506.9	5.5	53.6	-1.6	19.0	-1.97*
D-4	105	682.4*	45.7	54.2	505.2	5.6	55.4	-1.7	18.0	**-4.84***

* indicates satisfactory convergence to the posterior mode has not yet been achieved.
# results still to come.

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4 AIC = -2lnL+2n, where L is the Likelihood (i.e, excluding the contributions of the priors)
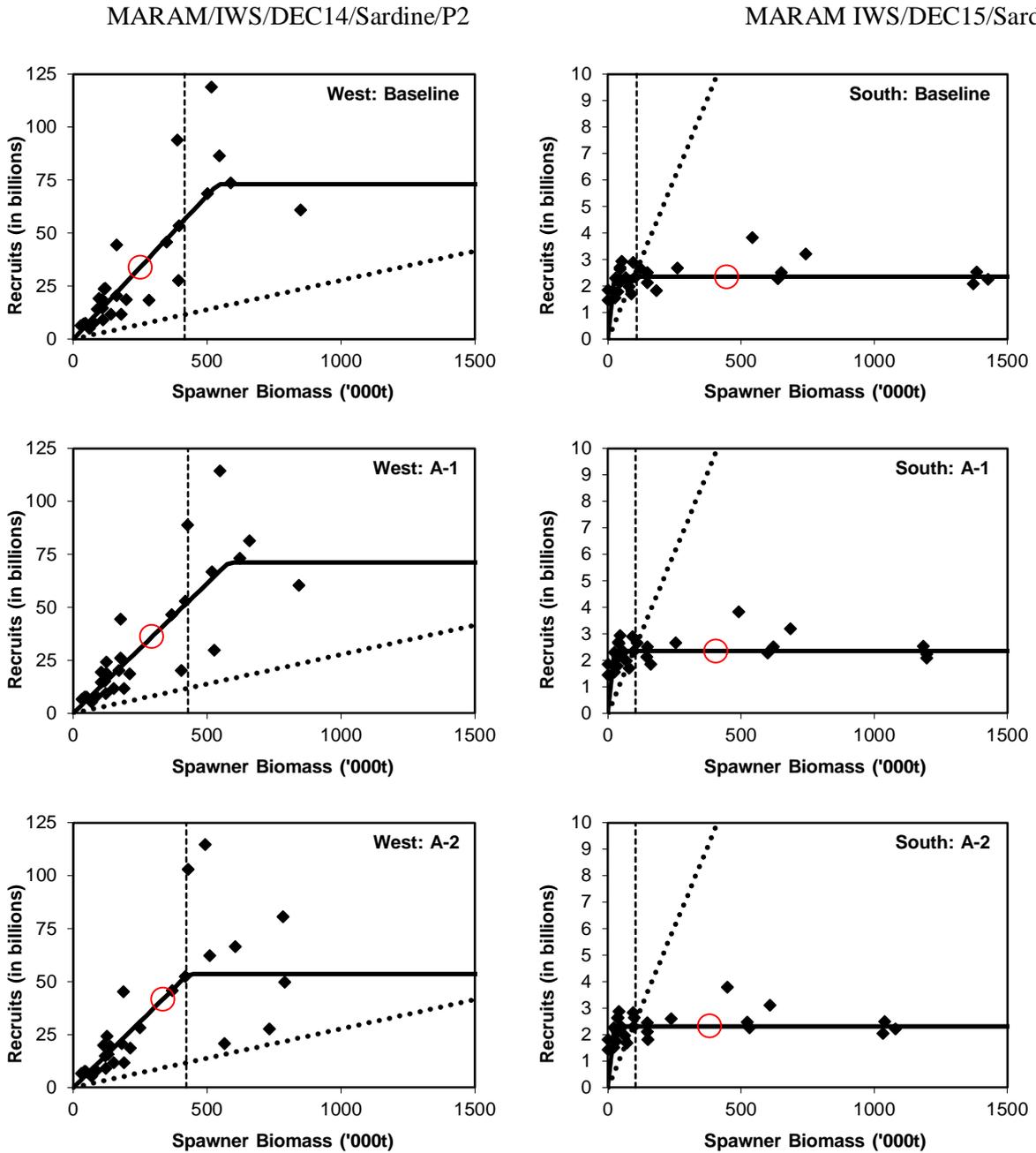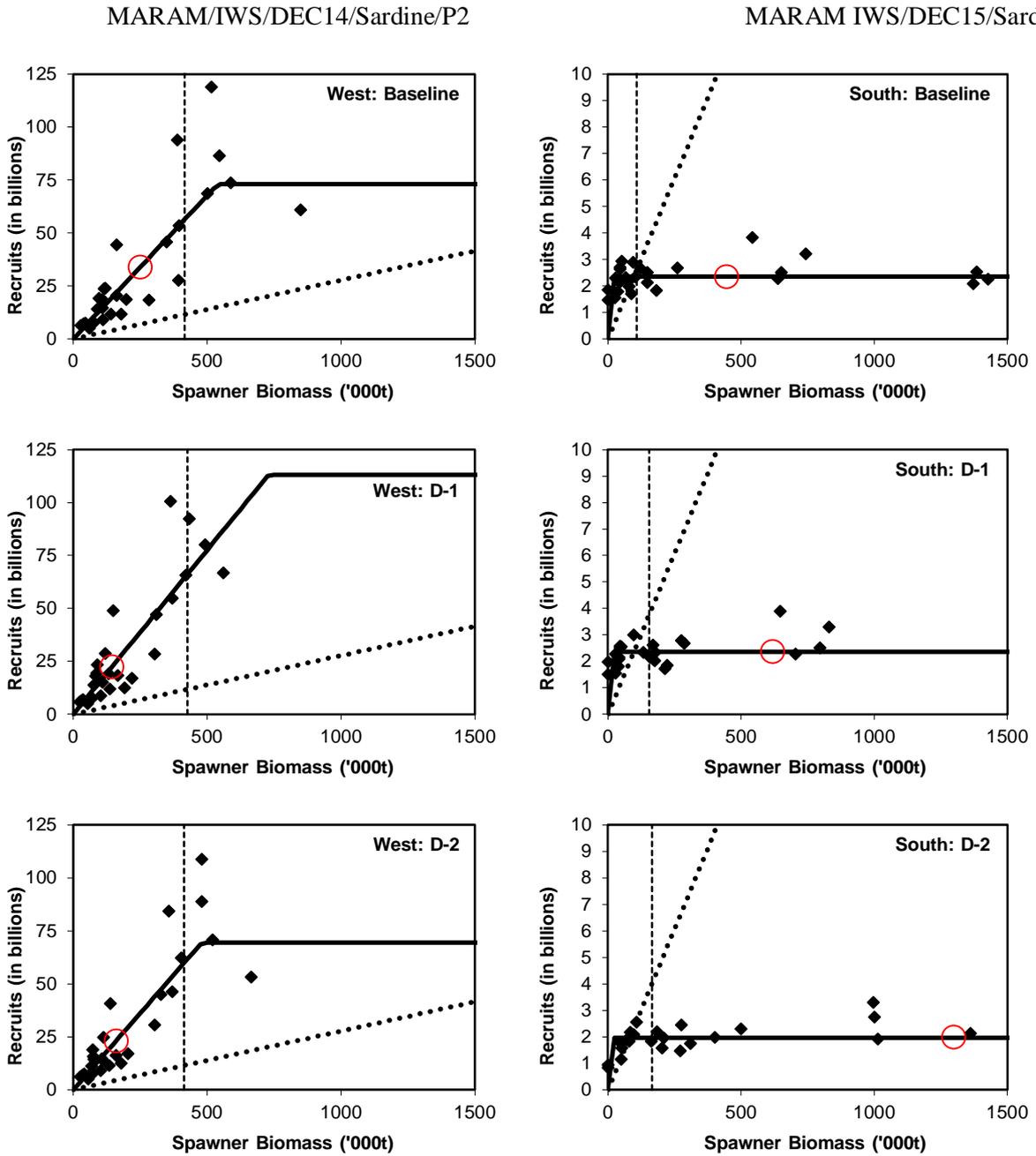
Figure 1. Model predicted sardine recruitment (in November) plotted against spawner biomass from November 1984 to November 2010 with the estimated Hockey stick stock recruitment relationship at the joint posterior mode for the Alternative A hypotheses. The vertical thin dashed line indicates the average 1991 to 1994 1+ biomass (the total population average was used in the definition of risk in OMP-04 and OMP-08 for a single sardine stock). The dotted line indicates the replacement line. The open red circles indicate the model estimated effective spawning biomass in November 2011. The lower set of plots compares the model predicted stock recruitment relationships between the baseline and the Alternative A hypotheses.
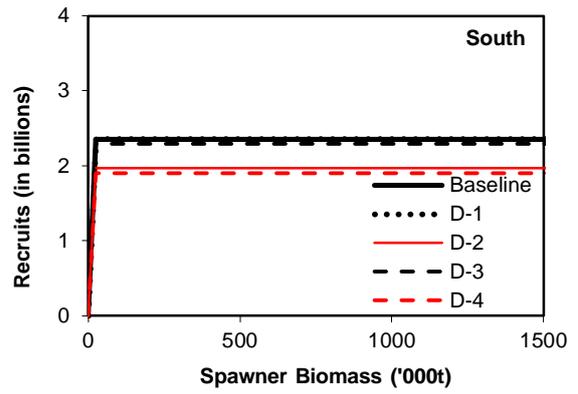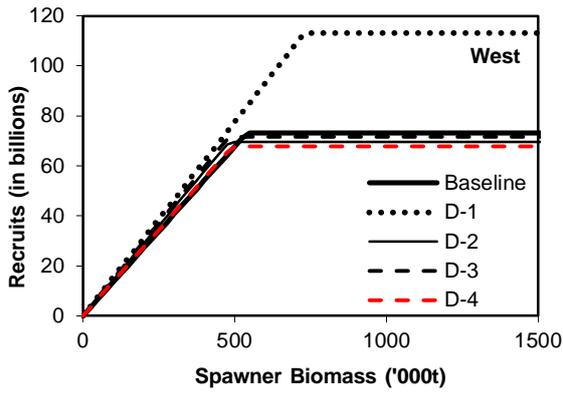
MARAM/IWS/DEC14/Sardine/P2   MARAM IWS/DEC15/Sardine/BG5
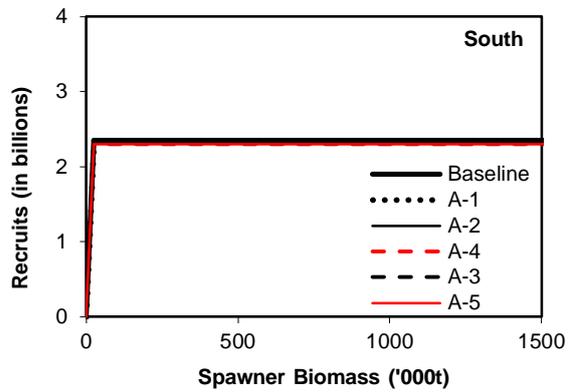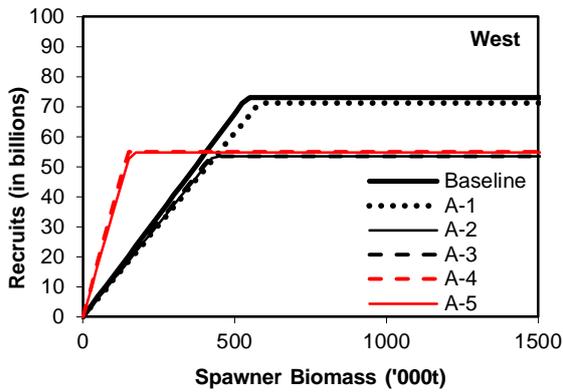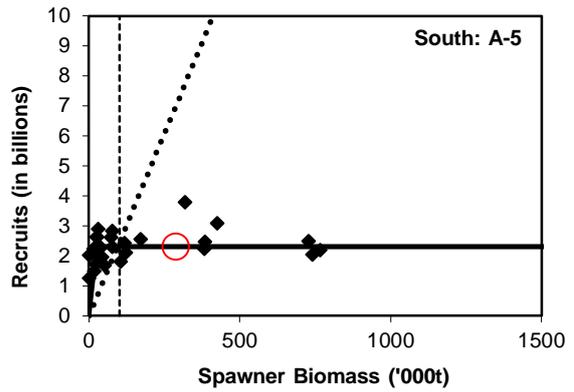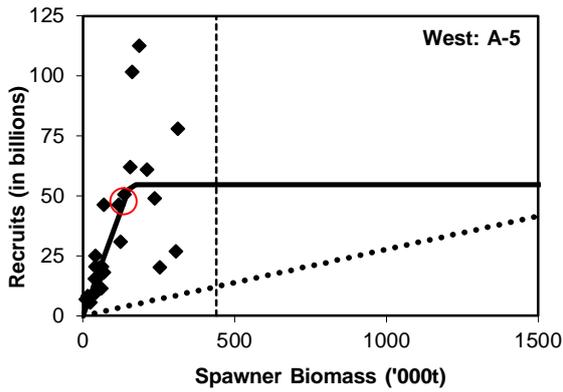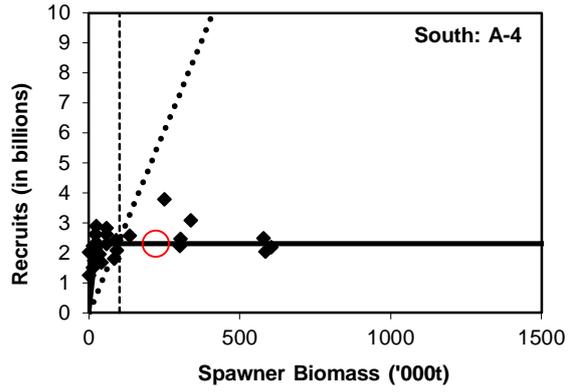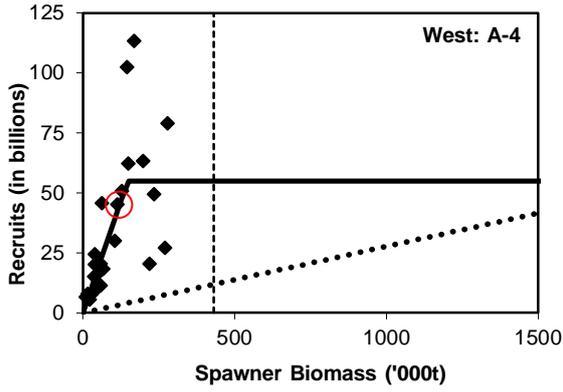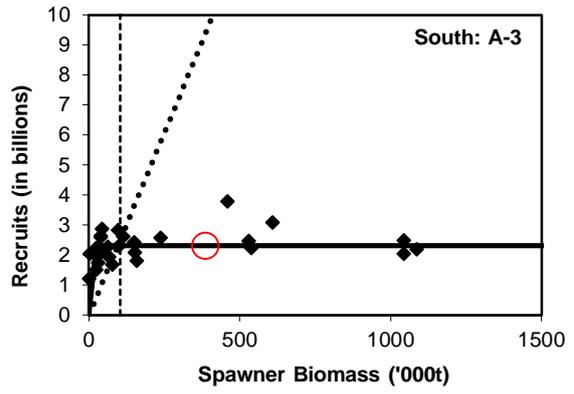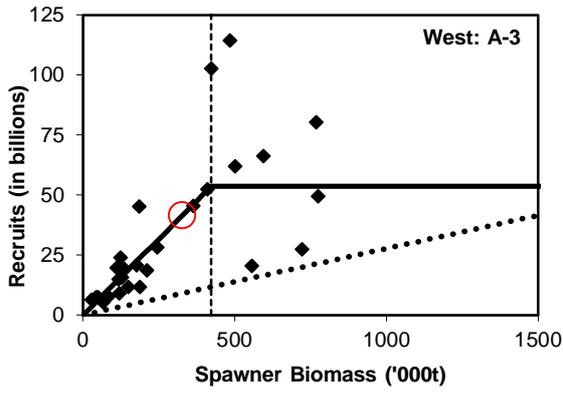
Figure 1 (continued).
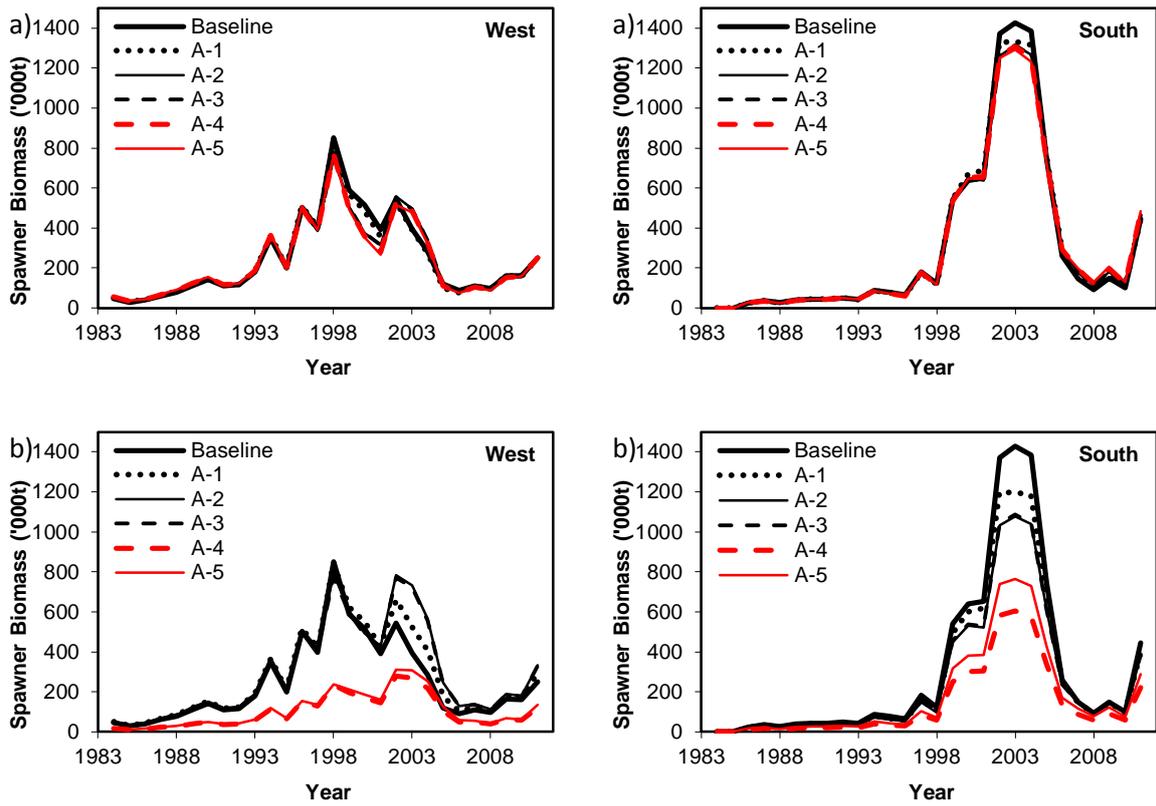
Figure 2. The a) actual and b) effective spawning stock biomass estimated by the baseline and alternative "A" hypotheses at the joint posterior mode.
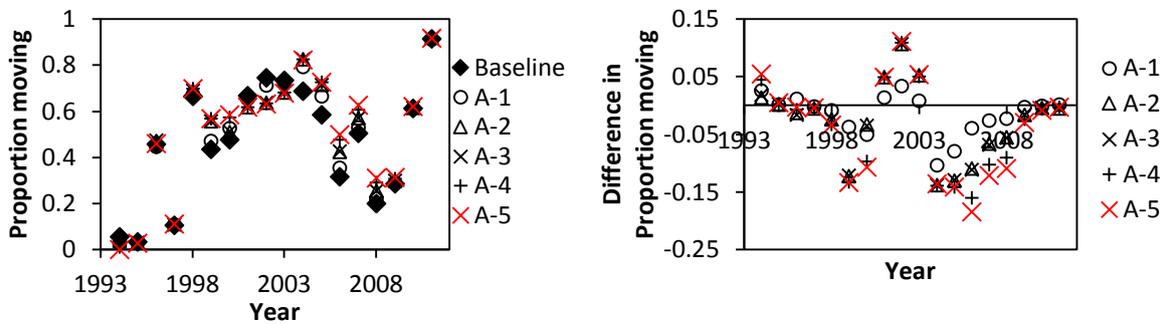
Figure 3. Model estimated proportion of recruits which move from the "west" stock to the "south" stock in November as they reach age 1 for the alternative "A" hypotheses at the joint posterior mode (no movement is modelled prior to 1994). The right hand plot shows the difference in this proportion between the baseline and these alternatives.
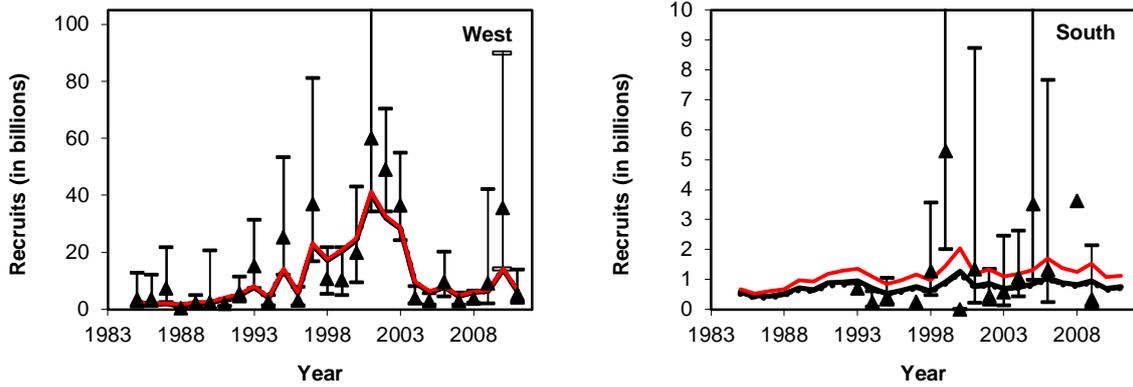
Figure 4. Acoustic survey estimated and model predicted sardine recruitment numbers from May 1985 to May 2011 for the baseline (solid), B-1 (dashed), B-2 (dotted) and B-3 (red line) hypotheses. The survey indices are shown with 95% confidence intervals.
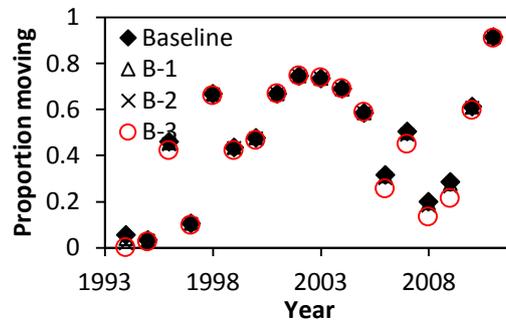
Figure 5. Model estimated proportion of recruits which move from the "west" stock to the "south" stock in November as they reach age 1 for the alternative "B" hypotheses at the joint posterior mode (no movement is modelled prior to 1994).

Figure 6. Model predicted sardine recruitment (in November) plotted against spawner biomass from November 1984 to November 2010 with the estimated Hockey stick stock recruitment relationship at the joint posterior mode for the Alternative D hypotheses. The vertical thin dashed line indicates the average 1991 to 1994 1+ biomass (the total population average was used in the definition of risk in OMP-04 and OMP-08 for a single sardine stock). The dotted line indicates the replacement line. The open red circles indicate the model estimated effective spawning biomass in November 2011. The lower set of plots compares the model predicted stock recruitment relationships between the baseline and the Alternative E hypotheses.
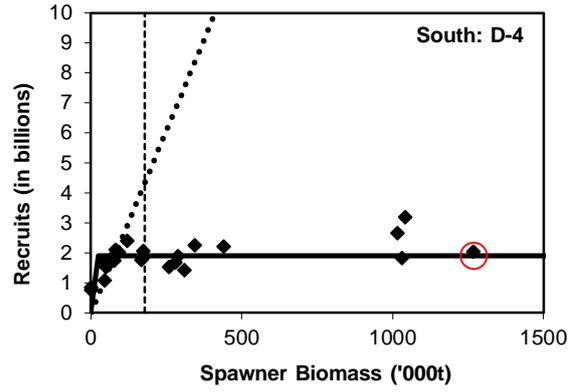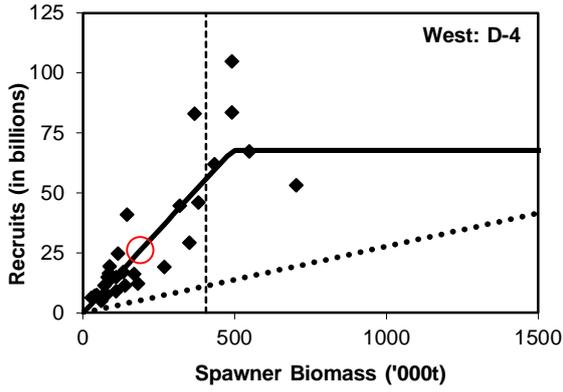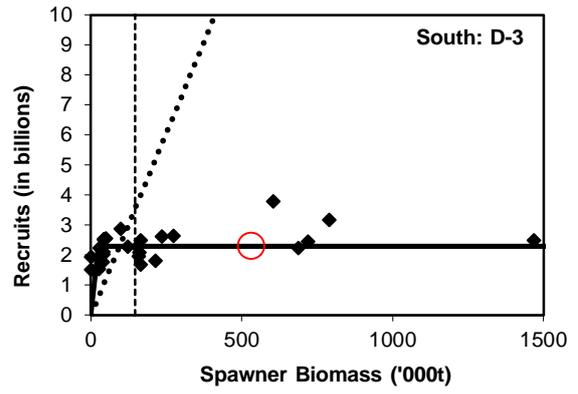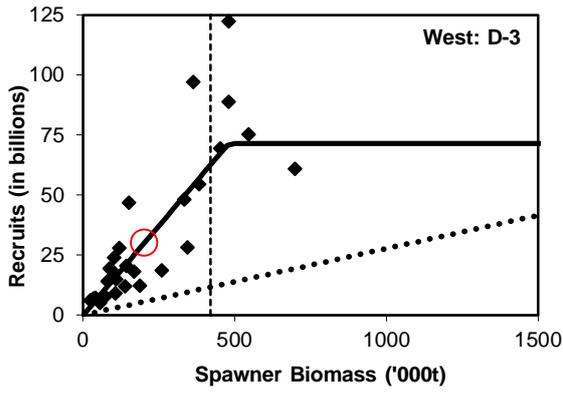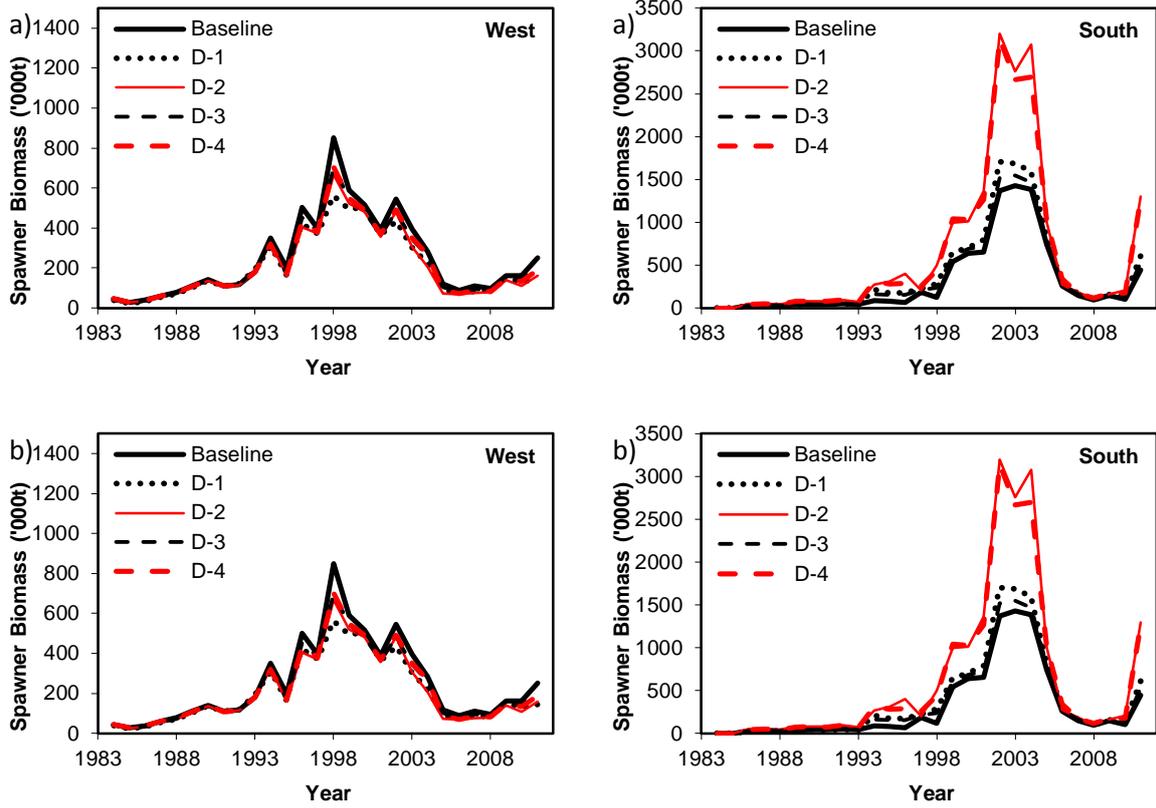
Figure 6 (continued).

Figure 7. The a) actual and b) effective spawning stock biomass estimated by the baseline and alternative "D" hypotheses at the joint posterior mode.
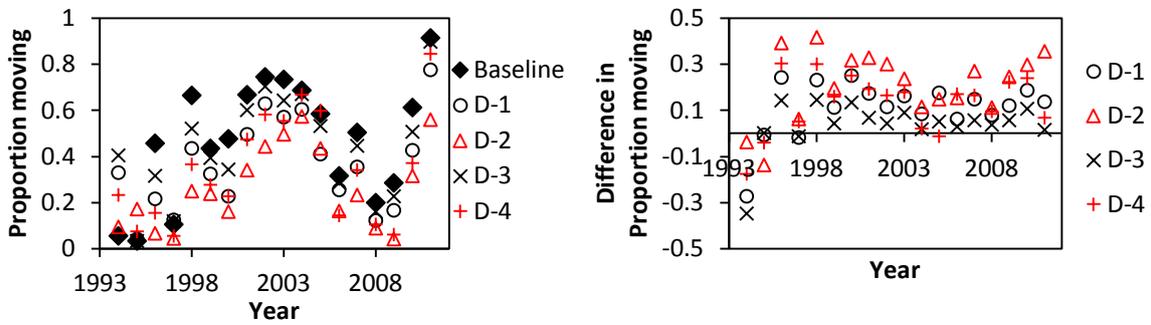

Figure 8. Model estimated proportion of recruits which move from the "west" stock to the "south" stock in November as they reach age 1 for the alternative "D" hypotheses at the joint posterior mode (no movement is modelled prior to 1994). The right hand plot shows the difference in this proportion between the baseline and these alternatives.
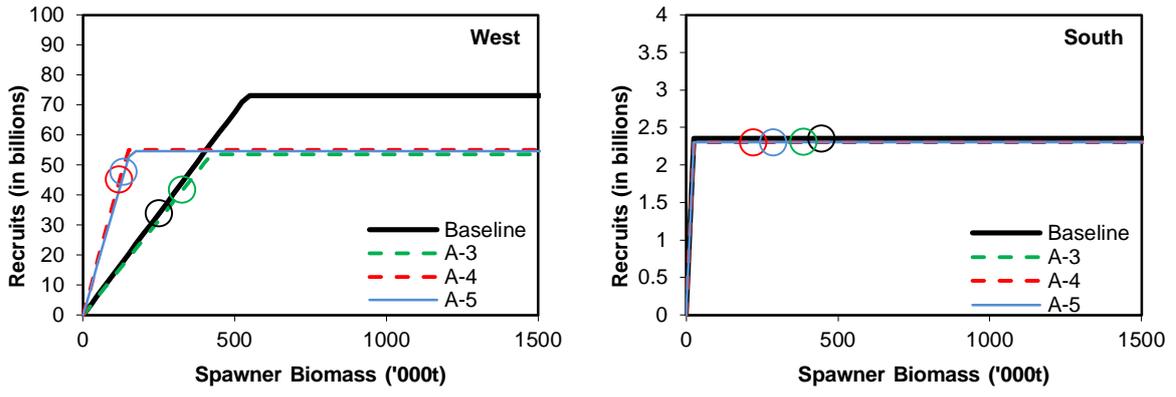
Figure 9. Estimated Hockey stick stock recruitment relationship at the joint posterior mode for the "preferred" alternative A hypotheses. The open circles indicate the model estimated effective spawning biomass in November 2011.