A proposal for determining the initial desirable maximum catch of directed sardine west of Cape Agulhas during 2017, with suggestions on how this might be achieved

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Butterworth (2016) outlined a draft process for setting the initial directed >14cm sardine TAC for 2017. This document expands on the detail of that draft process, with some changes/updates. Further, it provides initial projections from November 2015 to November 2017, assuming that the May 2016 survey estimate of recruitment was observed without error. Ideally the SWG-PEL will select a low probability for November 2017 projected 2+ biomass being below the inflection point of the hockey-stick stock recruitment curve at the meeting on 7th December, based on the initial results presented below. In addition, the SWG-PEL may need to select a percentage increase above the recommended west coast catch limit that could be used to recommend an initial directed >14cm sardine TAC. This latter step seems to need consideration because formal spatial restrictions will not at this stage be included on the permits with the initial TAC allocation. Thus, as a worst case scenario, the majority of this initial TAC may be caught on the west coast. The remaining steps in this process are proposed to be undertaken after the November 2016 hydroacoustic survey estimate of abundance becomes available.

Method for Projections

The following procedure is proposed to evaluate the maximum catch that would desirably be allowed west of Cape Agulhas during 2017.

1) 1000 samples of the following parameters are drawn from the preliminary[1] MCMC chains resulting from de Moor and Butterworth (2016):

   k_N^i – the bias in the November hydroacoustic survey estimate of total biomass for sardine

   $k_{j,r}^i$ – the bias in the May survey estimate of recruitment for sardine population component *j* (where *j* reflects west or south)

   $N_{j,2015,a}^i$ – the numbers at age $1 \le a \le 5^+$ in November 2015 for component *j*

   $S_{j,a}^i$ - the directed sardine commercial selectivity at age $1 \le a \le 5^+$ for component *j* where annual selectivity

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[1] These chains are considered preliminary as convergence diagnostics have not yet been checked, and the burn-in period was chosen "by eye". 1000 samples were randomly drawn from the 31.7 million samples to date, after a burn-in of 12 million and subsequent thinning by 2000.

is approximated by that estimated during quarters 2 and 3 of the most recent 5 years during conditioning, i.e. $S^i_{j,a} = \frac{1}{5}\sum_{y=2011}^{2015}\sum_l 0.5\left(S^i_{j,y,2,l}A^{com,i}_{j,y,2,a,l} + S^i_{j,y,3,l}A^{com,i}_{j,y,3,a,l}\right)$

$w^i_{j,a}$ – the November weight-at-age $0 \le a \le 5^+$ for component *j*, where $w^S_{j,a} = \frac{1}{5}\sum_{y=2011}^{2015}\sum_l w^S_{j,y,l}A^{sur}_{j,y,a,l}$

$B^{2+i}_{j=w,y}$ – the November 2+ biomass for component j for $1984 \le y \le 2015$

$N^i_{j=w,y,a=0}$ – the November recruits for component j for $1984 \le y \le 2015$

2) Assuming that 2+ biomass is a proxy for SSB[2], fit a hockey-stick stock recruitment relationship to $\{B^{2+i}_{j=w,y}, N^i_{j=w,y,a=0}\}$ for $1984 \le y \le 2015$, to get 1000 inflection points b^i, $1 \le i \le 1000$.
3) Assuming the May-June 2016 survey estimate of recruitment is without error, project forward 1000 trajectories to obtain 2+ biomass distributions in November 2017 (see Appendix and Figure A.1).
4) Calculate the probability of being below the inflection point, i.e. $p\left(B^{2+}_{j=w,2017} < b\right) = \sum_{i=i}^{1000} W^i p\left(B^{2+i}_{j=w,2017} < b^i\right)$ for a range of $C_{j,2017}$ from 0t to 50 000t. Initially the samples are equally weighted, i.e. $W^i = \frac{1}{1000}$.
5) The May-June survey estimate of total biomass of 122 960t (CV=0.425) west of Cape Agulhas and 232 925t (CV=0.887) south-east of Cape Agulhas is likely a negatively biased estimate given that the survey does not extend as far offshore as the November survey. The extent of this bias is unknown, and thus the biomass estimate cannot be used quantitatively in updating the weightings of Step 4), e.g. by fitting the model predicted total biomass to that observed in a likelihood. However, this value can be considered qualitatively when observing the distribution of biomass at 1 June as predicted by this model.
6) Considering the range of results from 4) and 5) above, the SWG-PEL needs to select an acceptably low (e.g. 5-10%) probability, p^{select}, that the 2+ biomass of the west component in November 2017 should be below the inflection point in the hockey stick curve.

7) Once the November 2016 hydroacoustic survey estimate of abundance is available, update the weighting in step 4) such that samples which closer reflect the observed total[3] biomass in November 2016 receive a higher weighting. Thus given:

$$-lnL^i_{Nov} = \frac{\left(ln\left(B^{NOV\,obs}_{j=w,2017}\right) - ln\left(B^i_{j=w,2016}\right)\right)^2}{2\left(CV^{NOV}_{j=w,2016}\right)^2},$$

the weighting W^i becomes $\frac{e^{lnL^i_{Nov}}}{\sum_{j=1}^{1000} e^{lnL^j_{Nov}}}$.

8) Find the value of $C_{j,2017}$ which gives $p\left(B^{2+}_{j=w,2017} < b\right) = p^{select}$.

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[2] Median (SSB/B^{2+}) is 1.46 for the west component and 0.96 for the south component between 1984 and 2015.

[3] Taken to be approximated by 1+ biomass in this projection.

Initial Projection Results

Figure 1 shows the posterior distribution of the inflection point in the hockey stick stock recruitment relationship from both the baseline Operating Model (de Moor and Butterworth 2016) and that which results when hockey stick stock recruitment curves are fit to the 1000 draws of 1984-2014 November 2+ biomass (as a proxy for spawner biomass) v November recruitment. (Note that the OM 2+ biomass for a particular sample need not necessarily always be less than spawner biomass since not all 2+ fish are fully mature.)

Figure 2 shows the distributions of projected biomass in May 2016, November 2016 and November 2017. Table 1a lists the proportions of projected 2^+ biomass in November 2017 below the inflection point of the hockey-stick stock recruitment curve. Table 1b lists the proportions of projected 2^+ biomass in November 2016 below the inflection point of the hockey-stick stock recruitment curve. These proportions are substantially lower than those projected for November 2017 as they do not take into account the low recruitment observed in May-June 2016.

The May-June 2016 survey estimate of total biomass was 122 960t (CV=0.425). While this cannot be used as a quantitative 'target' data point, it can be used to qualitatively inform on the weighting we should apply to the model predicted distribution. Figure 3 shows the model predicted distribution of this May recruit survey observation, with a median of 109 000t and average of 117 000t. The survey bias used in this calculation is shown in Figure 4.

Implications for the initial directed >14cm sardine TAC for 2017

DAFF would be unable to formally enforce restricting the west coast catch to about $C_{j,2017}$ (at least prior to the implementation of OMP-17), and SAPFIA have indicated a likely inability to "police" the "Gentleman's Agreement", particularly if the scientific recommendation is for a low catch on the west coast, in part because they do not represent all rights holders. Given these circumstances, the SWG-PEL have agreed that it may be desirable to restrict the initial directed >14cm sardine TAC below that which would be calculated under OMP-14, should that latter amount be appreciably higher than what the above method recommends could be caught on the west coast during 2017 without impairing future recruitment. The SWG-PEL thus need to consider the risk that an inappropriately large proportion of the initial directed >14cm sardine TAC may be taken on the west coast, and thus might need to agree what percentage, p, above $C_{j,2017}$ would be sufficiently precautionary as an initial directed >14cm sardine TAC.

In such circumstances, the SWG-PEL would recommend an initial directed >14cm sardine TAC which would be the minimum of that arising from OMP-14 and $\left(1+\frac{p}{100}\right) \times C_{j,2017}$.

As an example, if $C_{j,2017} = 60$ thousand tons, and the SWG-PEL decides on a value for p of 10%, then the initial directed >14cm sardine TAC would be the minimum of 66 thousand tons and that arising from OMP-14. Alternatively, if $C_{j,2017} = 20$ thousand tons, and the SWG-PEL decides on a value for p of 30%, then the initial directed >14cm sardine TAC would be the minimum of 26 thousand tons and that arising from OMP-14.

Further Discussion

To further aid discussions on this topic, Table 2 lists the initial directed sardine TAC which would result under OMP-14 for a range of survey estimates of biomass in November 2016. Figure 5 shows the model predicted 1+[4] November 2016 biomass adjusted for survey bias, i.e. this distribution compares directly with the list of possible survey observations in Table 2, with a median of 279 000t under the no movement scenario.

References

de Moor CL, and Butterworth DS. 2016. Assessment of the South African sardine resource using data from 1984-2015: Results at the joint posterior mode for the two mixing-stock hypothesis. DAFF: Branch Fisheries Document FISHERIES/2016/JUL/SWG-PEL/22REV2.

Butterworth DS. 2016. Draft process for setting initial directed sardine TAC for 2017. DAFF: Branch Fisheries Document FISHERIES/2016/NOV/SWG-PEL/68.

Coetzee JC, Merkle, D, Philips M, Geja Y, Mushanganyisi K, Shabangu F. 2016. Results of the 2016 Pelagic Recruitment Survey. DAFF: Branch Fisheries Document FISHERIES/2016/JUL/SWG-PEL/25rev.

Table 1a. The probability of the November 2017 2^+ biomass being below the inflection point of the hockey-stick stock recruitment curve, $p\left(B_{j=w,2017}^{2+} < b\right)$, for a range of west coast catches during 2017, $C_{j,2017}$, and a range of the proportion of sardine moving from the west to the south coast in November 2016.

$C_{j,2017}$	$move_{2016,1} = 0$	$move_{2016,1} = 0.1$	$move_{2016,1} = 0.37$[5]	$move_{2016,1} = 0.6$
0t	0.239	0.257	0.297	0.346
10 000t	0.261	0.275	0.325	0.385
20 000t	0.284	0.302	0.358	0.475
30 000t	0.313	0.334	0.426	0.543
40 000t	0.35	0.376	0.498	0.642
50 000t	0.404	0.438	0.560	0.714

[4] The biomass of very-recent recruitment is assumed here to be small.

[5] This is the median (and average) average proportion of 1-year-olds moving between 2010 and 2015.

Table 1b. The probability of the November 2016 2^+ biomass being below the inflection point of the hockey-stick stock recruitment curve, $p\left(B_{j=w,2016}^{2+} < b\right)$, for a range of the proportion of sardine moving from the west to the south coast in November 2015.

$C_{j,2016}$	$move_{2015,1} = 0$	$move_{2015,1} = 0.1$	$move_{2015,1} = 0.37$	$move_{2015,1} = 0.6$
0t	0.128	0.139	0.179	0.230
51 922t	0.202	0.215	0.255	0.291

Table 2. The initial directed >14cm sardine TAC as recommended by OMP-14 and the "Gentleman's Agreement" for a range of November 2016 survey estimates of biomass and a range of proportions of this biomass west of Cape Agulhas during November 2016, noting the proportion west of Cape Agulhas in November 2015 was 0.271.

			Initial TAC to be caught west of Cape Agulhas			
November 2016 survey estimate	Initial "total area" directed sardine TAC	Possible maximum "total area" directed sardine TAC	Proportion observed west of Cape Agulhas			
			0.20	0.40	0.60	0.80
100 000t	556t	1 111t	131t	186t	242t	298t
200 000t	13 889t	27 778t	3 271t	4 660t	6 049t	7 438t
300 000t	45 000t	99 000t	10 598t	15 098t	19 598t	24 098t
400 000t	70 001t	94 000t	16 485t	23 485t	30 485t	37 485t
500 000t	81 225	91 472	19 128t	27 251	35 373t	43 496t
600 000t	90 000t	90 000t	21 195t	30 195t	39 195t	48 195t
700 000t	90 000t		21 195t	30 195t	39 195t	48 195t

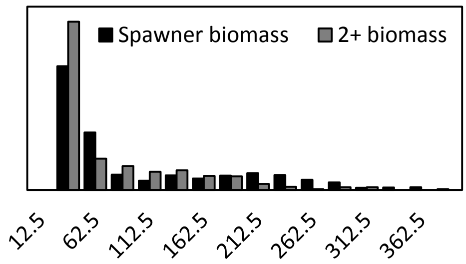

Figure 1. The posterior distribution of the inflection point in the hockey stick stock recruitment relationship from the baseline Operating Model (using spawner biomass) and that which results when stock recruitment curves are re-fit using November 2+ biomass as a proxy for spawner biomass.

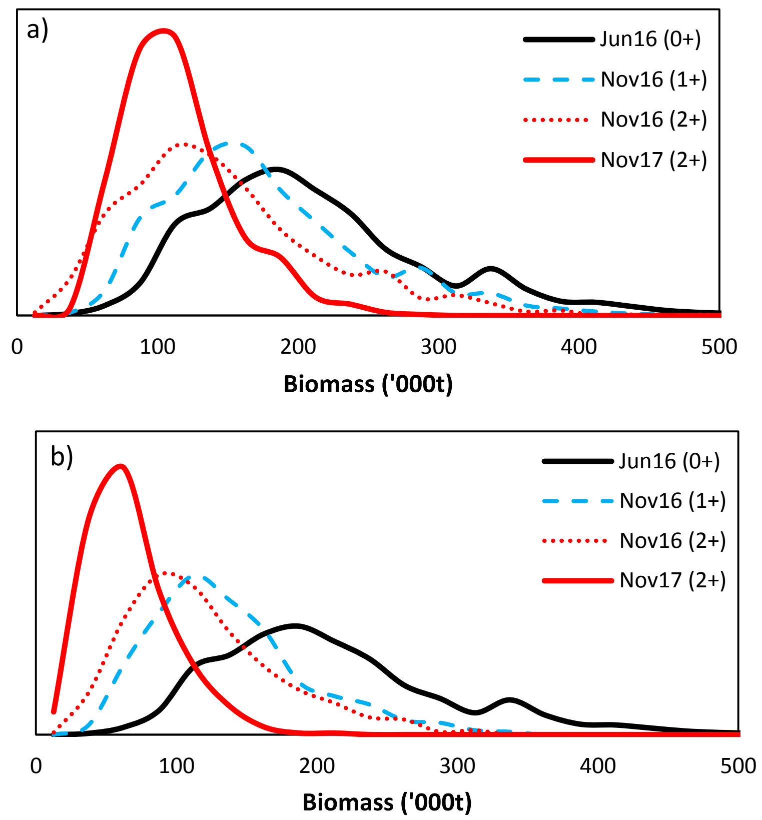

Figure 2. The distributions of projected "true" biomass west of Cape Agulhas in May 2016, November 2016 and November 2017 under a) the most optimistic scenario of zero west-to-south movement in November 2016 and zero 2017 catch and b) assuming 37% (the average of 2010 to 2015) of the 1-year-olds move from the west to the south coast in November 2016, with 30 000t catch on the west coast during 2017.

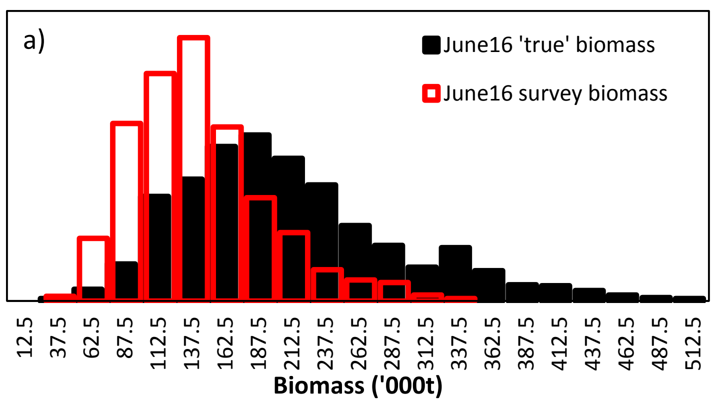

Figure 3. The predicted distribution of west coast biomass, i.e. $B^{obs}_{j,2016} = k^{i}_{j,r} B^{MAY\ i}_{j,2016}$, corresponding to the May-June 2016 survey estimate of recruit+adult biomass of 122 960t.

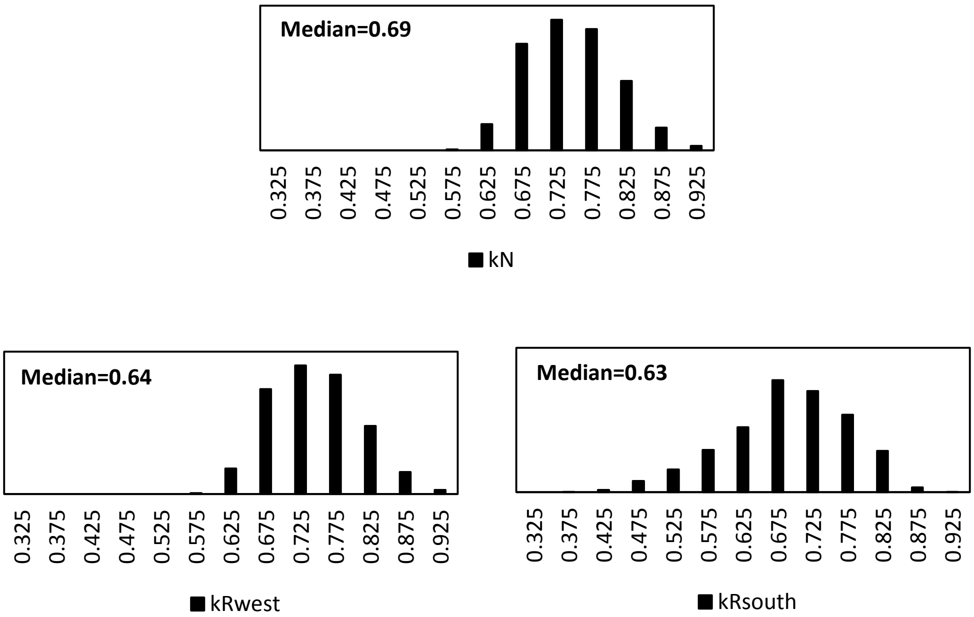

Figure 4. The posterior distributions of bias in the November and May hydroacoustic surveys used in these analyses.

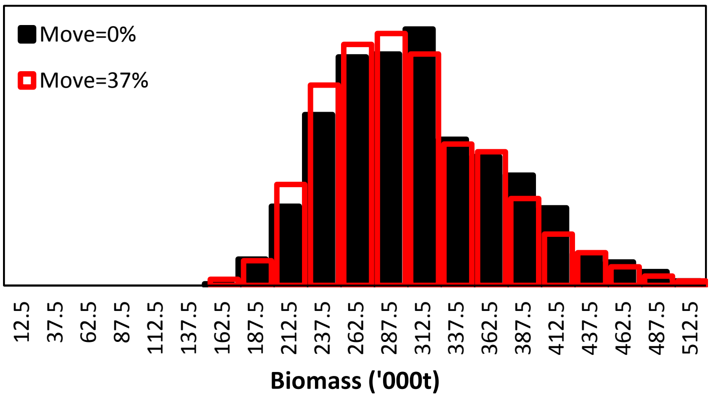

Figure 5. The model predicted total (i.e. west and south coast) 1+ biomass in November 2016 that is adjusted for survey bias, i.e. this distribution corresponds with that which would be observed by the November 2016 hydroacoustic survey if the May 2016 survey estimate of recruitment was without error.

Appendix

The assumption is made that the May-June 2016 survey estimate corresponds to 1 June and that catch is taken at a mid-point between any period considered during projection.

Numbers at age and total biomass at 1 June 2016:

$$N_{j,2016,o}^{MAY\ i} = N_{j,2016}^{obs} \Big/ k_{j,r}^{i}$$

$$N_{j,2016,a}^{MAY\ i} = \left(N_{j,2015,a}^{i} e^{-\frac{3.5}{12}\times M_a} - C1_{j,2016,a}^{i}\right) e^{-\frac{3.5}{12}\times M_a} \qquad 1 \le a \le 5+$$

$$B_{j,2016}^{MAY\ i} = \sum_{a=0}^{5+} N_{j,2016,a}^{MAY\ i} \left(\frac{\frac{5}{12}w_{j,a}^{i} + \frac{7}{12}w_{j,a+1}^{i}}{2}\right)$$

Numbers at age and 1+ biomass at 1 November 2016:

$$N_{j,2016,a}^{i} = \left(N_{j,2016,a-1}^{MAY\ i} e^{-\frac{2.5}{12}\times M_{a-1}} - C2_{j,2016,a-1}^{i}\right) e^{-\frac{2.5}{12}\times M_{a-1}} \qquad 1 \le a \le 4$$

$$N_{j,2016,5+}^{i} = \left(N_{j,2016,4}^{MAY\ i} e^{-\frac{2.5}{12}\times M_4} - C2_{j,2016,4}^{i}\right) e^{-\frac{2.5}{12}\times M_4} + \left(N_{j,2016,5+}^{MAY\ i} e^{-\frac{2.5}{12}\times M_{5+}} - C2_{j,2016,5+}^{i}\right) e^{-\frac{2.5}{12}\times M_{5+}}$$

$$B_{j,2016}^{i} = \sum_{a=1}^{5+} N_{j,2016,a}^{i} w_{j,a}^{i}$$

Numbers at age and 2+ biomass at 1 November 2017:

$$N_{j,2017,a}^{i} = \left(N_{j,2016,a-1}^{i} e^{-0.5\times M_{a-1}} - C_{j,2017,a-1}^{i}\right) e^{-0.5\times M_{a-1}} \qquad 2 \le a \le 4$$

$$N_{j,2017,5+}^{i} = \left(N_{j,2016,4}^{i} e^{-0.5\times M_4} - C_{j,2017,4}^{i}\right) e^{-0.5\times M_4} + \left(N_{j,2016,5+}^{i} e^{-0.5\times M_{5+}} - C_{j,2017,5+}^{i}\right) e^{-0.5\times M_{5+}}$$

$$B_{j,2017}^{2+\ i} = \sum_{a=2}^{5+} N_{j,2017,a}^{i} w_{j,a}^{i}$$

Here $M_0 = 1.0$ and $M_a = 0.8$ for $1 \le a \le 5^{+}$, and catches at age are calculated as follows:

$$C1_{j,2016,a}^{i} = N_{j,2015,a}^{i} e^{-\frac{3.5}{12}\times M_a} S_{j,a}^{i} F1_{j,2016}^{i} \quad 1 \le a \le 5+$$

$$C2_{j,2016,a=0}^{i} = N_{j,2016,0}^{MAY\ i} e^{-\frac{2.5}{12}\times M_0} F2_{j,2016}^{ByC\ i}$$

$$C2_{j,2016,a}^{i} = N_{j,2016,a}^{MAY\ i} e^{-\frac{2.5}{12}\times M_a} S_{j,a}^{i} F2_{j,2016}^{i} \quad 1 \le a \le 5+$$

$$C_{j,2017,a}^{i} = N_{j,2016,a}^{i} e^{-0.5\times M_a} S_{j,a}^{i} F_{j,2017}^{i} \quad 1 \le a \le 5+$$

with

$$F1_{j,2016}^{i} = \frac{C1_{j,2016}^{obs}}{\sum_{a=1}^{5+} N_{j,2015,a}^{i} e^{-\frac{3.5}{12}\times M_a} S_{j,a}^{i} \left(\frac{8.5}{12}w_{j,a}^{i} + \frac{3.5}{12}w_{j,a+1}^{i}\right)}$$

$$F2_{j,2016}^{i} = \frac{C2_{j,2016}^{obs}}{\sum_{a=1}^{5+} N_{j,2016,a}^{MAY\ i} e^{-\frac{2.5}{12}\times M_a} S_{j,a}^{i} \left(\frac{2.5}{12}w_{j,a}^{i} + \frac{9.5}{12}w_{j,a+1}^{i}\right)}$$

$$F2_{j,2016}^{ByC\ i} = \frac{By_{j,2016}^{obs}}{N_{j,2016,0}^{MAY\ i} e^{-\frac{2.5}{12}\times M_0} \left(\frac{8.5}{12}w_{j,0}^{i} + \frac{3.5}{12}w_{j,1}^{i}\right)}$$

$$F_{j,2017}^{i} = \frac{C_{j,2017}}{\sum_{a=1}^{5+} N_{j,2016,a}^{i} e^{-0.5\times M_a} S_{j,a}^{i} \left(0.5w_{j,a}^{i} + 0.5w_{j,a+1}^{i}\right)}$$

The observed data are May-June survey estimates of recruitment $N_{j=w,2016}^{obs} = 0.811$ billion and $N_{j=s,2016}^{obs} = 0.850$ billion (Coetzee et al. 2016), the >14cm catch from 1 November 2015 to 31 May 2016 $C1_{j=w,2016}^{obs} = 42.763$ and $C1_{j=s,2016}^{obs} = 12.096$ thousand tons, the >14cm catch from 1 June 2016 to 31 October 2016 $C2_{j=w,2016}^{obs} = 9.159$ and $C2_{j=s,2016}^{obs} = 10.664$ thousand tons, and the sardine juvenile bycatch from 1 June 2016 to 31 October 2016 $By_{j=w,2016}^{obs} = 3.397$ and $By_{j=s,2016}^{obs} = 0.030$ thousand tons.

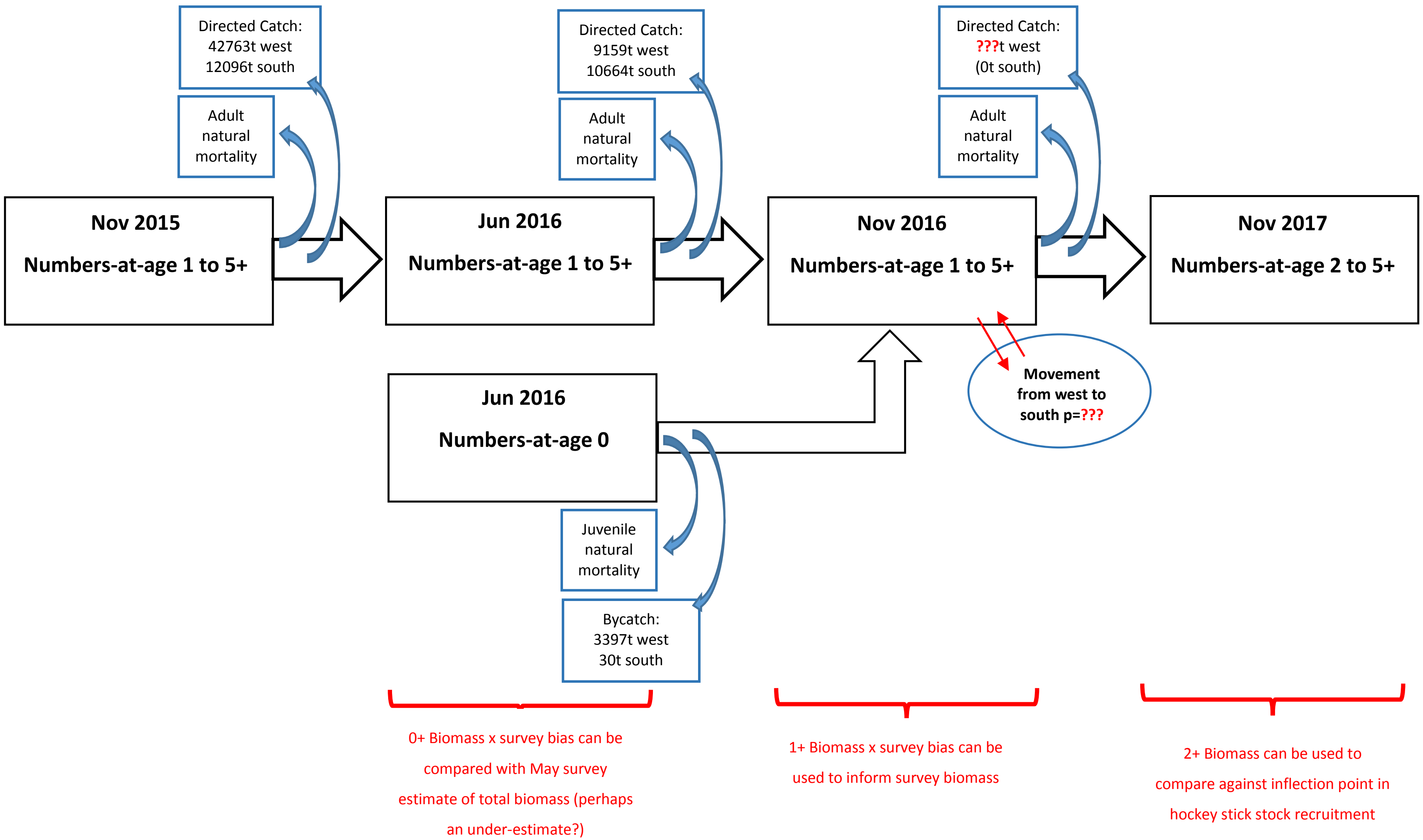

Figure A.1. A graphical representation of the projection model used in this analysis.