The data used in the 2019 sardine assessment

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Data to which the 2019 assessment of the South African sardine resource is to be conditioned are listed.

The data to which the South African sardine assessments are conditioned are not all raw data. Some data have already been subjected to analyses and refinements. These associated calculations are often done "behind the scenes" and their details are seldom recorded. This lack of record can result in a discontinuity in the method used to calculate data for subsequent assessments, particularly if assumptions made in the calculations are not documented and/or a new person becomes responsible for developing the data to be used for input to the assessment. This document serves to record the generation of the data used in the sardine assessment carried out in 2019 from the raw data.

Information on Ageing

Sardine age-length keys for the November surveys derived by Deon Durholtz are available by area (east and west of Cape Agulhas) for 1993, 1994, 1996, 2001 - 2004 and 2006 - 2009. Cynthia Mtengwane has compiled sardine age-length keys by area for the November surveys in 1993, 1994, 1996, 2001, 2003, 2004, 2006 - 2010. Age-length keys for the November surveys from 1984-1999 derived by Michael Kerstan are also available (De Oliveria 2003). Age-length keys for sardine commercial catch for some months each year from 1984 to 1999 were also derived by Michael Kerstan (De Oliveria 2003). Selected monthly age-length keys for sardine commercial catch between 2004 and 2009 have been derived by Cynthia Mtengwane. However, inconsistencies between these age-length keys derived by Kerstan and those from Durholtz and Mtengwane restricted the use of age-length keys from all readers in the assessment. In addition, Smith *et al*. (2011) recommended that these age-length keys not be used to calculate proportions-at-age for use in the assessments due to an inability to detect strong cohorts in the age data (which are known to be present through inference from the survey estimates of abundance). This may be due to problems with ageing and/or problems with the construction of the survey length-frequency data.

Sardine Commercial Data

Monthly directed sardine catch numbers are available for 1981 to 1983 (De Oliveria pers. comm.) but no LFs are available for these months. These data are not used in the assessment.

Monthly length frequencies were constructed for the sardine landings using the method in Appendix A. From 1987 onwards, these have been split by area (east and west of Cape Agulhas). For the single stock hypothesis, the catch tonnage and length frequencies by month are assumed to be equal to the combined catch tonnage east and west of Cape Agulhas[1].

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[1] The LFs assigned to sets slightly east of Cape Agulhas would likely have been from Gansbaai landings in a single area scenario, but due to the split in catches at Cape Agulhas, a LF from Mossel Bay area would instead be used. The difference between such single area and two-area LFs is assumed to be minor.

Between 1987 and 2011, sardine landings were categorized as either directed (>50% sardine mass in landing) or bycatch by the scale monitor. The bycatch was recorded as being either caught with anchovy or round herring, with the allocation determined by the species which formed >50% mass in the landing[2].

From 2012 onwards, the sardine landings have again been categorized as either directed >14cm (>50% sardine mass in landing) or bycatch by the scale monitor. The bycatch is now recorded as either 'small' (≤14cm) sardine with directed >14cm sardine, or else 'small' (≤14cm) or 'large' (>14cm) bycatch resulting from directed anchovy or round herring fishing. As fish of a similar size tend to shoal together, the assumption is made for this assessment, that the 'small' sardine bycatch is primarily bycatch with anchovy and the time series is comparable with the 1987-2011 time series of sardine bycatch with anchovy. Anchovy is seldom[3] landed with adult sardine and/or round herring. The 'large' sardine bycatch is assumed to be primarily bycatch with round herring and the time series is assumed comparable with the 1987-2011 time series of bycatch with round herring.

The sardine bycatch with anchovy (or 'small' sardine bycatch) is used separately in the assessment to the directed sardine catch and sardine bycatch with round herring. Quarterly data used in the assessments are taken over the months November *y*-1 to January *y* , February to April *y* , May to July *y* , and August to October *y*.

<u>Directed sardine and sardine bycatch with round herring</u>

The directed sardine and sardine bycatch with round herring length frequencies by area, month and year, i.e. the number of fish in length class l in area a during month m of year y, $N_{y,l,m,a}$, from 1984 to 2018 are stored in *SardineCatchLFs_West_DirectedandLargeBycatch.xlsx* and *SardineCatchLFs_East_DirectedandLargeBycatch.xlsx*, together with the observed tonnage in each month and year, $ObsT_{y,m,a}$. For 1984 to 1986 the monthly observed tonnages landed were obtained from length frequency data provided for the assessment in 2004. For calculation purposes, these 1984 to 1986 catch data are all treated as directed and round herring bycatch. The monthly catch tonnage is shown by area in Tables 1a and 1b.

Expected mass by length class and month is calculated as: $EM_{y,l,m} = 0.000011639 \times l_{mid}^{3.03155} \times N_{y,l,m}$ where l_{mid} is the mid-point of the length class considered and mass is in grams and length in millimetres (van der Lingen *et al*. 2006 with correction). The "raised" length frequency used in the assessment, is then calculated as follows: $\acute{N}_{y,m,l} = N_{y,m,l} \times \frac{ObsT_{y,m}}{\sum_l EM_{y,l,m}}$.

<u>Sardine bycatch with anchovy</u>

The sardine bycatch with anchovy length frequencies by area, month and year from 1987 to 2015 are stored in *SardineCatchLFs_West_AnchovyBycatch.xlsx* and *SardineCatchLFs_East_AnchovyBycatch.xlsx*, together with the observed tonnage in each month and year, $ObsT_{y,m,a}$. The monthly catch tonnages are given in Table 1c.

Small amounts of sardine bycatch with anchovy (totalling 81.9t) were recorded east of Cape Agulhas in 1992, 2007, 2008, 2010, 2011, 2013-2018. In the two stock hypothesis these bycatches are assumed to be taken west of Cape Agulhas with the

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[2] Note that the bycatch recorded in Sybase is exactly according to that reported by the scale monitors and does not necessarily match that recorded by this 50% sample allocation rule. The SWG-PEL-agreed categorization charts (Anon. 2004) have not been rigorously applied in practice to the data recorded in Sybase.

[3] Occasionally in the area from Cape Point to Cape Agulhas.

remainder of the anchovy bycatch. As there was no length frequency recorded with the 0.16t of small sardine bycatch east of Cape Agulhas in April 2007, this small catch was ignored.

These sardine bycatch with anchovy data are split between juvenile (0-year old) and adult catch as follows:
Let $N_{y,m,l}$ denote the number of sardine in length class l landed as bycatch with anchovy in month m of year y.
Juvenile sardine bycatch with anchovy landed in month m of year y is taken to be all sardine below a given cut-off length, i.e.

$$C_{y,m,0} = \sum_{l=lmin}^{<lcut(y,m)} N_{y,m,l}$$

Adult sardine bycatch with anchovy of length l landed in month m of year y, are all assumed to be 1 year olds, and are taken to be:
$C_{y,m,1} = \sum_{l=lcut(y,m)}^{lmax} N_{y,m,l}$.

The cut-off length, $lcut(y,m)$, taken to apply to May and June was set at that used during the recruit survey, which was originally determined from analyses of age-growth curves (1984-1995) but, because of the lack of reliable age information since the mid-1990s, based on a modal progression analysis (1996-2004) and more recently revised to the length at 20% maturity for years in which macroscopic gonad staging information is available (2005-2019) (Coetzee and Merkle 2007, Coetzee et al. 2018, given in Table 2). The cut-off length was decreased for months from May back to November, and increased from June through to October. This was done by considering the November survey length frequencies, both back from May to November of the previous year and forward to November of the current year. A faster growth rate was assumed in the earlier months:

Month	Number of length classes greater or less than the recruit survey cut-off length
November-December	-12 (-6cm)
January-February	-6 (-3cm)
March-April	-2 (-1cm)
May-June	0
July-August	+2 (+1cm)
September-October	+3 (+1.5cm)

This resulted in the following monthly cut-off lengths:

	October (y-1) to November (y)														
Month	1985	1986	1987	1988	1989	1990	1991	1992	1993	1994	1995	1996	1997	1998	1999
Nov-Dec	9.5	9.5	9.0	10.0	10.0	10.0	10.0	10.0	10.0	10.0	10.0	9.0	8.0	8.0	11.0
Jan-Feb	12.5	12.5	12.0	13.0	13.0	13.0	13.0	13.0	13.0	13.0	13.0	12.0	11.0	11.0	14.0
Mar-Apr	14.5	14.5	14.0	15.0	15.0	15.0	15.0	15.0	15.0	15.0	15.0	14.0	13.0	13.0	16.0
May-Jun	15.5	15.5	15.0	16.0	16.0	16.0	16.0	16.0	16.0	16.0	16.0	15.0	14.0	14.0	17.0
Jul-Aug	16.5	16.5	16.0	17.0	17.0	17.0	17.0	17.0	17.0	17.0	17.0	16.0	15.0	15.0	18.0
Sep-Oct	17.0	17.0	16.5	17.5	17.5	17.5	17.5	17.5	17.5	17.5	17.5	16.5	15.5	15.5	19.0

	October (y-1) to November (y)														
Month	2000	2001	2002	2003	2004	2005	2006	2007	2008	2009	2010	2011	2012	2013	2014
Nov-Dec	11.0	6.0	10.0	10.0	8.0	6.5	8.0	7.5	8.0	8.0	7.5	9.5	8.0	7.5	8.0
Jan-Feb	14.0	9.0	13.0	13.0	11.0	9.5	11.0	10.5	11.0	11.0	10.5	12.5	11.0	10.5	11.0
Mar-Apr	16.0	11.0	15.0	15.0	13.0	11.5	13.0	12.5	13.0	13.0	12.5	14.5	13.0	12.5	13.0
May-Jun	17.0	12.0	16.0	16.0	14.0	12.5	14.0	13.5	14.0	14.0	13.5	15.5	14.0	13.5	14.0
Jul-Aug	18.0	13.0	17.0	17.0	15.0	13.5	15.0	14.5	15.0	15.0	14.5	16.5	15.0	14.5	15.0
Sep-Oct	19.0	13.5	17.5	17.5	15.5	14.0	15.5	15.0	15.5	15.5	15.0	17.0	15.5	15.0	15.5

	October (y-1) to November (y)			
Month	2015	2016	2017	2018
Nov-Dec	8.0	7.5	6.5	-
Jan-Feb	11.0	10.5	9.5	-
Mar-Apr	13.0	12.5	11.5	-
May-Jun	14.0	13.5	12.5	-
Jul-Aug	15.0	14.5	13.5	-
Sep-Oct	15.5	15.0	14.0	-

A cut-off length of 15.5cm was assumed for May/June 1984, corresponding to both the former default cut-off length and to that of 1985 with similar November total abundances having been recorded in 1984 and 1985.

Juvenile catch prior to the survey

As catch is modelled quarterly, the observed sardine juvenile catch prior to the survey is required only from 1 May to the day before the survey commenced. This was calculated from the length frequencies of landings between 1 May and the day before the commencement of the survey (totalled over all catches and bycatches). The cut-off lengths used to calculate the recruit survey biomass, also used to calculate the recruit catch in May and June (see above) were applied. Inspector data (which include samples for species split) were not available in 1985 and 1986. Daily skippers' estimates of tonnage landed were, however, available for these years. Although the total tonnage landed in May 1985 and June 1986 was estimated by the skippers to be different to that arising from the source data, it was assumed that the proportion of catch taken before the survey compared to the whole month was the same between the skippers' estimates and the source data. Thus "raised" length frequencies for 1-19 May 1985 and 1-9 June 1986 were calculated as follows: $N_{l,partmonth} = N_{l,fullmonth} \times SkipperT_{partmonth}/SkipperT_{fullmonth}$, using the data in the below table.

	Days for which catch is required	Catch for the month (tons)	Skipper estimated catch for the month (tons)	Skipper estimated catch prior to the survey (tons)
May 1985	1-19th	3274	479	205
June 1986	1-9th	4042	970	609

These data are stored in *Sardine Catch Before Survey.xlsx* and given in Table 2.

November Survey Data

The time series of total biomass estimates and associated CVs from the acoustic surveys in November each year, corresponding to the standard survey area between Hondeklip Bay and Port Alfred, are given in Table 4. These data are stored in *SurveyData.xls*. The early part of this time series was updated by de Moor et al. (2008) so that the full time series corresponds to uncapped survey biomass determined with a new target strength formula (Coetzee et al. 2008) and corrected for attenuation.

Length frequencies are also available for the hydroacoustic surveys and are stored in *SardineSurveyLength.xlsx*.

Recruit Survey Data

The time series of recruit biomass and associated CVs from the May/June recruit surveys is given in Table 4. The recruit numbers at the time of the survey were calculated by summing the number of fish smaller than a cut-off length in the weighted length frequency (as per Method 1 of Appendix B). The average recruit weight is calculated by applying a length-weight regression to the weighted length frequency. This mean weight is then adjusted by the difference between the two biomasses (Method 1 of Appendix B). This calculated biomass and average recruit weight were calculated in a separate database, using the uncapped density per interval as input. The two biomass series are not identical due to the different methods of weighting used. A brief description of the two methods is given in Appendix B. Although not ideal, this difference has been narrowed from what has previously been used. This is a matter that needs to be addressed at some stage. In the assessments, the recruit numbers are used together with the CVs on recruit biomass. These survey data are stored in *SurveyData.xls*. The early part of this time series was updated by de Moor et al. (2008) and revised again in 2011 so that the full time series corresponds to uncapped recruitment determined with a new target strength formula (Coetzee et al. 2008) and corrected for attenuation. Adjustment is made for years in which the survey did not cover the full area west of Cape Infanta (Appendix C).

Parasite Data

The time series of infection prevalence of the "tetracotyle" type digenean endoparasite by length as sampled from November surveys between 2010 and 2018 is given in Table 5 (van der Lingen and Mushanganyisi 2019). This is the proportion of sardine-by-length that are infected with the parasite. The prevalence for west component sardine is estimated using data from fish collected to the west of Cape Agulhas (20°E), whereas that for south component fish is based on samples collected between 22°E (roughly Mossel Bay) and 30°E (roughly Port St Johns) to exclude age-1 individuals in the hypothesized mixing zone (20°-22°E) that may be western stock fish (Dunn et al. 2015). An alternative time series of south coast prevalence based on samples collected between Cape Agulhas and 30°E is used for a model sensitivity test.

Alternative information on the intensity of parasite infection, i.e. numbers of parasite per infected fish, is also available and may be included in later analyses. These data are stored in *Prevalence and Abundance by Length.xlsx*.

References

Coetzee, J.C., Merkle, D., de Moor C.L., Twatwa, N.M., Barange, M. and Butterworth D.S. 2008. Refined estimates of South African pelagic fish biomass from hydro-acoustic surveys: quantifying the effects of target strength, signal attenuation and receiver saturation. *African Journal of Marine Science* 30:205-217.

Coetzee, J.C., Geja, Y., van der Lingen, C.D. and Merkle, D. 2018. Deriving cut-off lengths for estimating recruitment indices from hydro-acoustic surveys. DAFF: Branch Fisheries Document FISHERIES/2018/APR/SWG-PEL/9.

de Moor, C.L., Butterworth, D.S. and Coetzee J.C. 2008. Revised estimates of abundance of South African sardine and anchovy from acoustic surveys adjusting for echosounder saturation in earlier surveys and attenuation effects for sardine. *African Journal of Marine Science* 30:219-232.

de Moor, C.L., and Butterworth, D.S. 2011. Extrapolation of recruit numbers to Cape Infanta in the years for which the survey only reached Cape Agulhas. DAFF: Brach Fisheries document FISHERIES/2011/AUG/SWG-PEL/42.

De Oliveira, J.A.A. 2003. The Development and Implementation of a Joint Management Procedure for the South African Pilchard and Anchovy Resources. PhD Thesis, University of Cape Town, South Africa.

Dunn, A., Haddon, M., Parma, A.M. and Punt A.E. 2015. International Review Panel Report for the 2015 International Fisheries Stock Assessment Workshop. MARAM International Stock Assessment Workshop, Cape Town, 30 November – 4 December 2015.

Smith, A.D.M., Fernandez, C., Parma, A., and Punt, A.E. 2011. International Review Panel Report for the 2011 International Fisheries Stock Assessment Workshop. 28 November – 2 December, 2011, University of Cape Town, South Africa.

van der Lingen, C.D., Fréon, P., Fairweather, T.P. and van der Westhuizen, J.J. 2006. Density-dependent changes in reproductive parameters and condition of southern Benguela sardine Sa*rdinops sagax*. *African Journal of Marine Science* 28:625-636.

van der Lingen CD and Petersen J. 2019. A description of parasite data (2010-2018) used in the sardine two mixing stock assessment model. FISHERIES/2019/FEB/SWG-PEL/02.

Table 1a. The monthly sardine commercial catch tonnage (in thousands of tons) landed as directed catch (1983-2018) or bycatch with the round herring fishery (1987-2011) or 'large' sardine bycatch (2012-2018), west of Cape Agulhas.

Year	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
1983											0.072	0.083
1984	1.980	6.802	4.975	6.520	5.114	1.361	0.010	0.000	0.000	0.261	0.131	0.000
1985	3.641	5.715	6.198	4.255	3.274	5.640	1.964	0.011	0.014	0.000	0.000	0.000
1986	1.310	7.319	8.638	3.539	2.714	4.042	2.855	0.162	0.060	0.000	0.000	0.000
1987	3.675	6.322	7.013	5.638	1.851	1.398	0.524	0.218	0.066	0.000	0.000	0.000
1988	1.824	5.312	2.739	5.892	3.904	4.159	2.624	1.323	0.353	0.208	0.912	0.657
1989	1.374	2.549	7.463	4.339	2.639	2.979	1.938	0.774	0.178	0.037	0.176	0.072
1990	3.017	6.014	7.676	6.569	9.338	4.825	3.587	5.148	1.715	0.695	0.344	0.428
1991	2.525	6.128	4.017	6.159	7.451	5.552	5.699	3.993	1.586	1.098	0.124	0.188
1992	0.781	5.147	5.595	2.331	1.967	7.055	2.877	5.347	6.051	1.088	0.292	0.941
1993	4.637	7.868	6.511	4.301	6.452	5.292	1.028	0.990	0.908	1.166	1.306	1.709
1994	1.692	6.264	11.375	7.879	16.378	6.225	6.696	7.297	4.662	5.206	1.224	0.377
1995	2.702	6.036	11.133	6.255	13.839	6.430	5.848	14.945	8.313	12.834	5.350	0.336
1996	2.891	9.022	9.449	7.745	10.287	7.736	5.651	7.590	8.834	10.340	11.219	1.468
1997	1.212	8.445	10.830	12.309	13.970	6.769	13.759	11.877	17.852	7.654	3.164	0.369
1998	2.384	8.419	14.266	6.244	8.491	13.170	13.223	18.716	11.303	14.341	4.447	0.814
1999	2.220	0.225	5.196	5.432	12.910	8.390	13.705	14.801	14.946	6.235	22.781	10.454
2000	0.000	2.458	7.796	10.812	12.949	16.912	11.126	12.413	10.336	19.398	15.934	1.796
2001	2.280	10.687	17.207	13.329	12.713	11.208	5.872	8.497	4.327	25.530	25.739	28.928
2002	0.106	12.317	14.810	26.716	12.163	8.193	8.168	13.312	22.815	25.341	47.652	29.528
2003	3.895	25.308	29.125	21.233	14.750	12.139	6.205	1.838	3.677	22.969	59.235	18.043
2004	8.484	40.646	31.707	17.499	30.774	18.458	15.263	3.619	25.090	18.682	60.672	19.235
2005	0.211	19.855	29.290	18.272	1.009	0.158	1.118	0.130	0.067	4.268	10.148	1.410
2006	1.123	0.907	19.201	5.685	0.593	1.061	0.214	0.304	11.908	19.009	15.628	7.344
2007	3.474	7.503	5.919	5.780	7.019	1.667	3.602	4.877	6.615	3.899	2.850	1.175
2008	0.000	0.767	8.000	7.459	1.455	3.664	1.179	1.195	0.000	7.055	9.012	2.913
2009	0.049	9.052	17.895	12.210	7.563	5.036	3.192	1.911	0.063	0.243	0.161	0.003
2010	0.805	7.418	13.821	9.120	9.261	6.335	6.774	3.008	2.184	0.037	8.920	0.673
2011	0.628	7.671	15.555	7.643	6.199	3.998	11.941	6.616	6.664	2.890	0.126	0.026
2012	5.037	14.860	13.816	10.880	9.071	6.410	1.049	0.850	3.006	4.842	5.715	0.000
2013	1.837	12.260	12.554	11.435	6.904	1.146	0.000	0.000	0.220	2.504	3.797	0.897
2014	5.941	12.185	13.043	9.193	0.946	0.031	0.105	2.890	1.902	4.486	4.534	1.582
2015	1.003	9.537	11.030	4.463	1.082	4.397	1.532	2.311	0.564	9.923	14.476	1.578
2016	0.088	12.841	10.964	4.691	2.966	2.712	0.034	0.165	2.488	4.873	3.258	0.541
2017	0.265	0.546	8.300	1.959	1.148	0.009	0.006	0.007	0.831	1.138	8.292	4.994
2018	0.123	3.913	8.418	2.859	0.232	0.014	0.090	0.016	0.011	5.656	3.060	1.974

Table 1b. The monthly sardine commercial catch tonnage (in thousands of tons) landed as directed catch (1989-2018) or bycatch with the round herring fishery (1989-2011) or 'large' sardine bycatch (2012-2018), east of Cape Agulhas. There was no catch east of Cape Agulhas prior to 1989.

Year	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
1989	0.000	0.000	0.167	0.000	0.000	0.000	0.000	0.004	0.000	0.000	0.047	0.000
1990	0.011	0.031	0.153	0.061	0.046	0.031	0.059	0.014	0.000	0.000	0.057	0.016
1991	0.010	0.224	0.114	0.158	0.272	0.074	0.000	0.000	0.000	0.230	0.134	0.164
1992	0.039	0.155	0.544	0.387	0.338	0.201	0.013	0.056	0.126	0.352	0.205	0.051
1993	0.097	0.234	0.378	0.318	0.227	0.196	0.005	0.152	0.161	0.119	0.142	0.270
1994	0.011	0.633	0.270	0.315	0.561	0.607	0.534	0.481	0.144	0.395	0.072	0.345
1995	0.365	0.743	0.605	0.062	0.481	0.159	0.309	0.135	0.257	0.837	0.594	0.395
1996	0.064	0.533	0.456	0.400	1.073	0.731	0.625	0.539	0.672	0.398	1.136	0.915
1997	0.093	0.290	0.741	0.362	0.640	0.369	1.234	0.134	0.105	0.298	0.000	0.000
1998	0.012	0.000	0.536	0.612	0.972	1.156	0.554	0.069	0.168	0.016	0.100	0.000
1999	0.708	0.061	0.413	0.692	0.817	0.943	0.255	0.408	0.457	0.709	1.006	0.623
2000	0.000	0.271	0.541	0.754	1.444	1.133	0.138	0.688	0.357	0.172	0.505	0.044

Table 1b (continued).

Year	Jan	Feb	Mar	Apr	May	Jun	Jul	Sep	Aug	Oct	Nov	Dec
2001	0.135	0.304	0.537	0.497	0.657	0.992	1.253	1.798	2.178	1.481	1.152	0.296
2002	0.000	0.885	0.671	0.678	2.493	2.880	4.275	4.873	3.314	3.051	2.712	1.419
2003	0.586	2.005	2.172	2.669	6.255	7.391	9.603	6.849	9.180	6.531	6.066	1.693
2004	0.534	1.660	2.543	4.306	7.630	10.285	10.250	15.521	9.307	9.738	4.287	1.393
2005	0.468	4.889	5.332	10.422	19.516	24.672	25.615	18.544	18.181	9.052	16.047	2.232
2006	0.947	6.454	10.630	12.736	28.192	25.894	17.695	8.775	3.450	3.823	3.469	3.114
2007	0.441	6.538	10.762	12.977	16.470	15.113	7.227	4.603	3.252	0.160	2.033	1.608
2008	0.344	2.088	3.175	13.837	8.529	3.685	7.192	2.254	0.236	1.055	1.055	0.567
2009	0.671	2.725	4.318	6.829	7.009	4.400	3.328	0.374	0.932	1.267	0.876	1.412
2010	0.814	2.443	3.156	2.836	3.460	3.256	3.030	3.262	2.607	0.292	0.032	0.905
2011	0.419	3.115	3.551	2.018	4.591	3.571	3.719	4.794	2.347	0.905	1.330	0.434
2012	1.048	2.582	4.278	4.027	5.513	4.092	1.958	0.863	0.807	0.215	0.312	0.437
2013	0.476	1.900	2.732	4.032	4.811	6.063	5.114	5.657	1.741	2.457	0.015	0.210
2014	0.088	0.669	3.832	3.782	6.940	6.277	9.034	1.683	1.696	0.439	0.000	0.000
2015	0.000	0.003	0.347	3.988	7.164	3.915	3.333	2.246	0.172	0.000	0.000	0.000
2016	0.000	0.036	0.004	1.592	10.245	3.921	3.800	2.726	0.000	0.062	0.000	0.000
2017	0.041	0.119	0.318	0.001	1.593	0.807	0.067	0.000	0.061	0.540	0.854	0.797
2018	0.033	0.294	0.767	0.806	2.492	1.040	1.193	0.029	0.550	1.193	1.518	0.807

Table 1c. The monthly sardine commercial catch tonnage (in thousands of tons) landed as bycatch with the anchovy fishery (1987-2011) or 'small' sardine bycatch (2012-2018), west of Cape Agulhas. These data include the small amounts of sardine landed east of Cape Agulhas.

Year	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
1987	0.018	0.187	0.280	1.415	0.329	1.462	1.521	1.407	0.206	0.000	0.000	0.000
1988	0.032	0.291	0.115	0.058	1.216	2.391	0.520	0.724	0.154	0.689	0.235	0.000
1989	0.135	2.144	0.970	1.783	2.988	1.576	0.399	0.000	0.000	0.000	0.000	0.000
1990	0.019	0.193	0.477	1.012	2.073	3.797	0.012	0.000	0.000	0.000	0.000	0.000
1991	0.010	0.074	1.473	2.778	0.518	2.174	0.029	0.005	0.000	0.000	0.000	0.000
1992	0.142	0.501	0.465	2.456	1.668	2.565	2.281	2.767	0.277	0.008	0.000	0.000
1993	0.070	0.179	0.500	1.397	1.376	0.204	0.619	1.552	0.559	0.163	0.000	0.000
1994	0.286	1.972	1.683	1.359	4.447	1.936	0.039	3.460	0.032	0.000	0.000	0.000
1995	0.046	0.026	1.024	0.735	1.890	4.306	5.076	6.133	0.447	1.970	0.535	0.000
1996	1.015	1.931	0.689	0.624	1.846	1.960	0.007	0.000	0.000	0.004	0.000	0.000
1997	0.073	0.006	0.005	0.002	0.243	0.267	1.469	0.735	3.226	0.863	0.000	0.000
1998	0.028	1.118	0.143	1.762	3.674	4.492	0.960	0.183	0.697	0.262	0.000	0.000
1999	0.000	0.000	0.318	0.381	1.364	2.288	0.490	0.730	1.393	0.482	0.089	0.000
2000	0.000	0.000	1.403	1.798	1.897	1.146	0.611	0.317	0.030	0.021	0.000	0.000
2001	0.001	0.244	0.243	0.981	2.258	2.623	1.098	3.431	1.291	1.689	0.046	0.028
2002	0.040	0.185	0.000	0.353	0.402	1.836	1.297	5.681	2.709	0.000	0.000	0.009
2003	0.000	0.000	0.182	1.845	2.137	4.290	1.130	0.118	0.280	0.462	0.130	0.000
2004	0.000	0.017	0.002	0.956	3.298	0.474	0.706	0.604	0.186	0.000	0.003	0.000
2005	0.000	0.072	0.995	1.279	1.507	0.384	0.393	0.260	0.520	0.266	0.131	0.000
2006	0.000	0.000	0.142	0.352	0.698	2.303	2.764	0.980	1.818	0.065	0.006	0.000
2007	0.000	0.003	0.061	0.724	1.972	0.365	0.202	0.291	0.123	0.191	0.000	0.004
2008	0.000	0.042	0.156	0.503	1.461	0.756	0.289	0.490	0.137	0.090	0.273	0.004
2009	0.000	0.066	0.181	0.776	0.382	0.327	0.360	0.564	0.059	0.081	0.010	0.000
2010	0.088	0.187	1.856	2.124	2.512	5.356	4.166	1.598	0.036	0.046	0.015	0.000
2011	0.008	0.066	0.162	1.523	3.372	1.257	3.787	1.215	0.000	0.000	0.000	0.000
2012	0.553	0.913	0.600	0.948	2.856	0.653	0.253	0.190	0.216	0.495	0.017	0.000
2013	0.053	0.000	0.000	0.625	2.010	0.633	0.006	0.000	0.005	0.000	0.055	0.000
2014	0.000	1.071	1.247	1.957	1.550	0.015	0.026	0.112	0.046	0.009	0.000	0.000
2015	0.000	1.677	4.226	2.335	4.633	0.414	0.057	0.008	0.003	0.002	0.001	0.000
2016	0.001	0.808	0.094	3.781	3.844	2.205	0.153	0.323	0.572	0.020	0.001	0.000
2017	0.018	0.213	0.175	1.410	1.861	0.274	0.330	0.054	0.010	0.144	0.211	0.013

Table 1c (continued).

Year	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
2018	0.003	0.045	0.133	0.327	0.548	0.083	0.106	0.176	0.036	0.051	0.034	0.053

Table 2. The date of the commencement of the annual recruit survey; the cut-off lengths used to estimate juvenile sardine from the recruit surveys; and juvenile sardine catch (in billions) from 1 May to the day before the annual recruit survey.

Year	Date of commencement of survey	Time of the recruit survey after 1 May	Cut-off length (cm) for sardine juveniles in the survey	Juvenile sardine catch between 1 May and the start of the survey	
				West of Cape Agulhas	East of Cape Agulhas
1985	20-May	0.613	<15.50	0.14369	0.00000
1986	10-Jun	1.300	<15.50	0.29243	0.00000
1987	20-Jul	2.613	<15.00	0.19502	0.00000
1988	27-Jun[4]	1.867	<16.00	0.29401	0.00000
1989	08-Jun[5]	1.233	<16.00	0.34199	0.00000
1990	22-Jun	1.700	<16.00	0.72152	0.00000
1991	07-May	0.194	<16.00	0.00840	0.00000
1992	13-May	0.387	<16.00	0.02896	0.00000
1993	21-May	0.645	<16.00	0.04235	0.00005
1994	05-May	0.129	<16.00	0.06712	0.00000
1995	10-Jun	1.300	<16.00	0.52989	0.00000
1996	05-Jun	1.133	<15.00	0.33035	0.00000
1997	17-May	0.516	<14.00	0.03477	0.00001
1998	20-May	0.613	<14.00	0.42147	0.00000
1999	10-May	0.290	<17.00	0.02230	0.00009
2000	15-May	0.452	<17.00	0.10745	0.00006
2001	05-May	0.129	<12.00	0.00031	0.00000
2002	05-May	0.129	<16.00	0.03253	0.00000
2003	14-May	0.419	<16.00	0.07321	0.00070
2004	08-May	0.226	<14.00	0.03025	0.00000
2005	13-May	0.387	<12.5	0.08528	0.00002
2006	19-May	0.581	<14.0	0.03335	0.00000
2007	18 May	0.548	<13.5	0.05973	0.00000
2008	21 May	0.645	<14.0	0.09930	0.00000
2009	15 May	0.452	<14.0	0.02565	0.00000
2010	27 May	0.839	<13.5	0.22688	0.00090
2011	27 May	0.839	<15.5	0.39873	0.02860
2012	16 June	1.500	<14.0	0.22346	0.00021
2013	23 May	0.710	<13.5	0.13087	0.00000
2014	10 May	0.290	<14.0	0.00007	0.00000
2015	22 May	0.677	<14.0	0.18432	0.00000
2016	8 Jun	1.233	<13.5	0.48125	0.00000
2017	12 Jun	1.367	<12.5	0.18132	0.00000
-	-	-	-	-	-
2019	7 Jun[6]	1.200	<12.0		

[4] The first station was on 27th June 1988, although the first acoustic interval was only logged after midnight, i.e. on 28th June 1988.
[5] The first station was on 8th June 1989, although the first acoustic interval was only logged after midnight, i.e. on 9th June 1989.
[6] The first station was on the 5th June 2019, although the first acoustic interval was logged on the 7th June 2015.

Table 3. Sardine total biomass (in tons) as far as Port Alfred and associated CV from the November acoustic survey.

Area	Hondeklip Bay to Port Alfred		Hondeklip Bay to Cape Agulhas		Cape Agulhas to Port Alfred	
Year	Sardine Biomass	CV	Sardine Biomass	CV	Sardine Biomass	CV
1984	48378	1.118	48009	1.127	369	0.644
1985	45013	0.509	25457	0.680	19556	0.767
1986	299797	0.848	238230	1.054	61566	0.672
1987	111285	0.630	94165	0.734	17120	0.693
1988	134362	0.957	128043	1.005	6319	0.525
1989	256655	0.274	198328	0.334	58327	0.397
1990	289876	0.352	248855	0.382	41020	0.905
1991	597858	0.395	517180	0.444	80678	0.675
1992	494157	0.658	247756	0.560	246401	1.191
1993	560019	0.427	480822	0.488	79198	0.603
1994	518354	0.370	389730	0.432	128624	0.709
1995	844727	0.713[7]	364324	0.302[8]	480402	1.229
1996	529456	0.471	257763	0.352	271693	0.849
1997	1224632	0.329	964835	0.322	259797	0.982
1998	1607328	0.251	1082547	0.341	524781	0.305
1999	1635410	0.212	708029	0.324	927381	0.280
2000	2292380	0.500	726230	0.633	1566150	0.670
2001	2309600	0.142	669617	0.313	1639983	0.154
2002	4206250	0.227	1184713	0.247	3021538	0.300
2003	3564171	0.197	1343118	0.300	2221053	0.258
2004	2619301	0.333	296108	0.432	2323193	0.372
2005	1048991	0.300	75604	0.524	973386	0.321
2006	712557	0.346	177889	0.414	534667	0.441
2007	252199	0.351	53138	0.541	199061	0.421
2008	384080	0.422	211871	0.528	172209	0.682
2009	501575	0.271	262175	0.285	239400	0.474
2010	508363	0.235	309465	0.328	198897	0.314
2011	1037060	0.235	182825	0.187	854235	0.283
2012	345054	0.345	186109	0.517	158945	0.440
2013	611763	0.346	467613	0.432	144150	0.443
2014	444500	0.291	195786	0.476	248715	0.361
2015	363230	0.297	98467	0.312	264763	0.391
2016	258575	0.353	183356	0.409	75219	0.690
2017	334804	0.449	107173	0.346	227631	0.640
2018	90768	0.502	34845	0.359	55922	0.783

[7] The 1995 survey had a single stratum A from Hondeklip Bay to Cape Point. This stratum has subsequently been split into A (Hondeklip Bay to Cape Columbine) and B (Cape Columbine to Cape Point), which results in a small adjustment to the stratum size and thus the biomass. The biomass given here is that corrected following this stratum adjustment, and following the same calibration as applied to 1984 to 1997 to account for saturation of the acoustic signal in previously used echosounders and estimates of attenuation in dense sardine schools (de Moor et al. 2008). The adjustments were small, from 843944t and 363542t to 844727t and 364324t for the full area and west of Cape Agulhas, respectively. However, due to time constraints, and the expectation that the impact on the CV will be small, the CV has not yet been re-calculated based on the revised strata sizes.

Table 4. Sardine recruitment (in thousands of tons and numbers in billions) from Hondeklip Bay to Cape Infanta and associated CV from the recruitment acoustic survey. The mean recruit weight is also given (in grams). The sardine recruitment and associated CV from Cape Infanta to Cape St Francis is also given in years that the survey extended sufficiently far eastwards. Blank cells correspond to years/areas for which data are not available, e.g. the survey did not reach Cape St Francis.

Year	Hondeklip Bay to Cape Infanta					Cape Infanta to Cape St Francis				
	Biomass (Method 1 of App B)	Biomass (Method 2 of App B)	CV	Mean Weight	Numbers	Biomass (Method 1 of App B)	Biomass (Method 2 of App B)	CV	Mean Weight	Numbers
1985[8]	37.424	37.636	0.649	10.420	3.592					
1986[9, 10]	45.336	43.839	0.609	12.284	3.705					
1987[9, 11]	90.525	90.742	0.554	12.266	7.409					
1988[9, 11]	4.461	4.790	0.462	10.134	0.442					
1989[9, 11]	47.394	46.879	0.426	22.176	2.145					
1990[9, 11]	27.317	28.567	1.079	10.920	2.511					
1991	22.864	22.769	0.269	11.939	1.915					
1992	68.554	69.608	0.363	12.170	5.633					
1993	108.133	109.591	0.367	7.096	15.238					
1994	58.091	57.208	0.324	21.886	2.654	19.496	18.227	0.555	28.028	0.696
1995	195.250	194.506	0.378	7.691	25.388	4.528	3.388	0.467	19.141	0.237
1996	52.678	48.154	0.453	16.441	3.204					
1997	340.160	342.363	0.402	9.229	36.856					
1998	124.952	129.664	0.360	11.660	10.716	5.238	5.207	0.540	19.642	0.267
1999	220.589	219.249	0.376	21.255	10.378	58.613	53.909	0.519	45.419	1.290
2000	265.489	264.452	0.390	13.273	20.002	168.591	165.955	0.495	31.870	5.290
2001	553.538	559.079	0.287	9.216	60.065	0.000	0.003	0.713	9.932	0.000
2002	610.344	595.913	0.182	12.417	49.153	41.495	37.613	0.958	31.103	1.334
2003	508.911	501.624	0.209	13.963	36.448	19.948	19.553	0.553	43.572	0.458
2004	25.871	26.003	0.342	6.326	4.089	4.187	4.477	0.732	7.191	0.582
2005	16.307	16.437	0.352	5.706	2.858	9.315	9.721	0.448	16.132	0.577
2006	47.898	45.804	0.403	5.039	9.506	61.333	62.444	0.654	17.539	3.497
2007	31.343	34.905	0.343	10.466	2.995	28.705	30.886	0.932	16.602	1.729
2008	25.337	24.157	0.266	6.195	4.090					
2009	59.765	57.181	0.776	6.434	9.289	64.730	63.827	1.013	17.792	3.638
2010	477.437	479.609	0.473	13.423	35.569	6.984	6.781	0.924	20.076	0.348
2011[12]	66.213	69.771	0.396	11.418	5.831					
2012	100.306	100.265	0.316	12.560	7.986					
2013	114.312	111.810	0.417	9.082	12.586	5.849	6.097	0.509	26.639	0.220
2014	24.171	25.073	0.622	12.179	1.985	28.866	28.186	0.677	23.181	1.245
2015	132.552	143.768	0.554	21.180	6.258	16.199	17.004	0.607	23.934	0.677
2016	13.910	12.392	0.425	17.151	0.811	20.728	20.827	0.887	24.394	0.850
2017	26.083	23.598	0.531	3.633	7.180	26.810	25.694	0.560	15.228	1.761
2018	No survey									

[8] The 1985 survey began in Mossel Bay and ended in Namibia. This survey included a single stratum from east of Danger Point to Mossel Bay. This full area is included in the survey estimate and thus the estimate is higher than that which would correspond to a survey area west of Cape Infanta only. It is thus not strictly comparable with the rest of the time series, but given the low sardine recruit densities observed between Cape Infanta and Mossel Bay, it is considered acceptable for this assessment.

[9] The time series of recruitment biomass and numbers between 1985 and 1997 were updated to account for saturation of the acoustic signal in previously used echosounders and estimates of attenuation in dense sardine schools (de Moor et al. 2008 and subsequently updated in 2011 after correcting an error in the way interval densities were split between adults and recruits). This early part of the time series was revised using a regression of available recruit data from 1998 to 2006. The time series of recruitment from 2005 onwards has recently been revised following a revision in the cut-off lengths (Coetzee et al. 2019). The regression analysis based on 1997-2006 data should, therefore, be updated. The extent of the impact of two year's data on this regression is unknown at this stage. However, given current time constraints and because the (potentially small) correction would only apply to the early part of the time series, this update has been delayed.

[10] Biomass and numbers west of Cape Infanta were estimated by taking that observed up to east of Danger Point and increasing by 0.4% (Appendix C)

[11] Biomass and numbers west of Cape Infanta were estimated by taking that observed up to east of Cape Agulhas and increasing by 0.4%.

[12] Biomass and numbers west of Cape Infanta were estimated by taking that observed up to Cape Agulhas and increasing by 3% (App. C).

Table 5a. The number of sardine sampled by length class for the "tetracotyle" type digenean endoparasite, west and east of Cape Agulhas.

	West of Cape Agulhas							
cm	2010	2011	2012	2013	2014	2015	2016	2018
10	3		5				30	15
10.5	9		11		2		19	14
11	7	1	21		5		25	13
11.5	3	2	43	1	5		29	34
12	16	1	32	4	2		33	33
12.5	23	4	23	8	5		38	30
13	35	9	14	25	6		44	11
13.5	33	11	10	36	12	3	64	10
14	40	9	13	22	22	3	42	3
14.5	33	3	16	17	21	3	53	3
15	30	2	11	8	23	5	43	4
15.5	21	8	11	3	6	6	43	1
16	24	8	3		11	7	28	1
16.5	14	22	7	2	7	16	14	
17	9	17	5	4	14	44	13	
17.5	3	73	8	8	14	48	5	1
18	12	76	10	10	18	14	9	
18.5	17	98	18	11	13	24	12	
19	17	91	15	6	11	21	30	1
19.5	15	36	13	9	14	22	44	
20	3	28	4		7	16	28	
20.5	1	7	2	1	3	5	18	
21		2	2		2	3	2	
21.5		1				3		
22		3				4		
22.5		5				7		
23						9		

	East of Cape Agulhas (excluding data between 20 and 22°E)							
cm	2010	2011	2012	2013	2014	2015	2016	2018
10					3		18	5
10.5					5	6	5	7
11					2	12	2	17
11.5	9				5	26		22
12	23				5	21	2	22
12.5	55	1			3	26	1	11
13	53				13	32		11
13.5	41	1	1		19	37		6
14	14		2		16	22	1	4
14.5	9	2	7		13	22	2	7
15	4	1	7		4	21		10
15.5	10	2	8		2	28	3	5
16	3	7	8			13		13
16.5	11	24	12			15	2	2
17	9	11	9			24		3
17.5	1	41	3			20		2
18	3	21	2			19		
18.5		59	2		1	9		1
19	1	30	1		4	7	1	
19.5	3	36	2		6	7		
20		3	2		15	14	3	
20.5		2	1		19	7	3	
21					8	3		
21.5		1			3	2	2	
22								
22.5								
23								

	East of Cape Agulhas (including data between 20 and 22°E)							
cm	2010	2011	2012	2013	2014	2015	2016	2018
10					3		41	18
10.5					9	6	10	26
11	3	4		1	4	12	5	51
11.5	19	10		2	6	26	2	54
12	45	10		0	5	21	2	62
12.5	78	14		11	3	26	1	45
13	70	2		20	13	32		25
13.5	62	12	1	41	20	37		9
14	22	11	2	19	16	22	2	6
14.5	11	22	7	5	13	22	4	8
15	7	3	7		4	21	2	10
15.5	13	8	8		2	28	10	5
16	3	8	8	1		13	5	13
16.5	11	29	12	1		15	8	2
17	9	14	9			24	12	3
17.5	1	60	3	2		20	6	2
18	3	35	2			19	4	1
18.5		80	2		1	9	1	1
19	1	42	1		4	7	8	
19.5	3	45	2		6	7	14	
20		7	2		15	14	16	
20.5		2	1		19	7	11	
21		0			8	3	3	
21.5		1			3	2	6	
22								
22.5								
23								

Table 5b. The number of sardine infected by length class with the "tetracotyle" type digenean endoparasite, west and east of Cape Agulhas.

	West of Cape Agulhas								East of Cape Agulhas (excluding data between 20 and 22°E)								East of Cape Agulhas (including data between 20 and 22°E)							
cm	2010	2011	2012	2013	2014	2015	2016	2018	2010	2011	2012	2013	2014	2015	2016	2018	2010	2011	2012	2013	2014	2015	2016	2018
10	0		0				5	0					0		0	0					0		0	0
10.5	0		3		0		4	0					0	0	0	0					2	0	0	0
11	0	0	5		0		4	0					0	0	0	0	0	1		0	0	0	0	0
11.5	0	0	5	1	1		5	1	1				0	4		0	1	5		0	0	4	0	0
12	0	0	4	3	0		6	0	1				0	1	0	0	1	0			0	1	0	0
12.5	1	1	1	2	1		8	0	4	0			0	0	0	0	4	2		1	0	0	0	0
13	1	0	0	7	1		6	0	2				0	0		0	2	0		3	0	0		0
13.5	4	0	0	11	2	0	13	0	7	0	0		0	0		0	8	2	0	5	0	0		0
14	5	2	1	8	6	0	7	0	3		0		0	1	0	0	3	1	0	2	0	1	0	0
14.5	2	0	2	6	2	1	9	0	0	1	0		0	0	0	0	0	7	0	0	0	0	0	0
15	6	0	0	5	4	0	15	1	0	1	0		0	1		0	0	1	0		0	1	0	0
15.5	5	3	2	1	3	0	9	0	0	1	0		0	1	0	0	0	3	0		0	1	1	0
16	9	3	0		2	1	12	0	0	1	0			0		0	0	1	0	1		0	1	0
16.5	7	3	0	2	2	1	5		0	1	0			1	0	0	0	1	0	0		1	1	0
17	5	6	2	0	6	8	5		1	3	0			3		0	1	4	0			3	2	0
17.5	2	17	5	5	5	10	4	0	0	11	0			3		0	0	13	0	1		3	0	0
18	1	6	4	10	13	3	7		0	5	0			4			0	7	0			4	1	0
18.5	11	24	10	9	11	4	10			18	1		0	3		0		23	1		0	3	0	0
19	9	22	5	5	8	3	23	0	0	10	1		2	1	1		0	16	1		2	1	4	
19.5	6	5	6	8	11	7	31		1	12	0		3	3			1	16	0		3	3	4	
20	3	5	1		5	0	20			1	1		11	1	1			3	1		11	1	7	
20.5	1	2	2	1	2	1	13			0	0		15	1	0			0	0		15	1	4	
21		1	1		2	1	2						8	2							8	2	2	
21.5		0				1				1			2	1	0			1			2	1	2	
22		2				0																		
22.5		3				3																		
23						5																		

Appendix A: Pelagic sample allocation

The sample allocation method is the process whereby a length frequency (LF) is allocated to every commercial landing, enabling the transformation of the catch to its raised length frequency (RLF). The commercial catch data and field station length frequency data are entered and stored on a Sybase database on the DAFF network. Length frequency data from the observer program (2001 to 2011) and Industry canneries (2011 to 2012 and presently ongoing) are included in the calculation. The calculations are performed in Access.

Species

For the assessments which serve as the operating models to test Operational Management Procedures it is necessary to calculate LFs for anchovy (*Engraulis encrasicolus)* and sardine (*Sardinops sagax)* though LFs for round herring (*Etrumeus whiteheadii)* and horse mackerel (*Trachurus trachurus capensis)* are also generated for every run.

Data sources

- Commercial catch: The skipper completes a skipper form for every trip and records the estimated catch per set and a pelagic 10′ by 10′ block position. Every landing is sampled for its species composition and weighed. The fisheries inspectors started the task of scale monitor and hence the catch sheet is referred to as the inspector's form. Normally this function is contracted to a private entity. Skipper data are available on Sybase from 1984 onwards but inspector data were obtained only from 1987. DAFF field station personnel collect data sheets and enter the information on Sybase.
- Field station samples: DAFF field station personnel collect random samples at the major pelagic fishing harbors for species composition and length frequency (Capricorn Fishing Monitoring was contracted from 2002 until 2005 to man St. Helena Bay and Gansbaai). Samples of industrial fish such as anchovy and round herring are obtained from the top of the hold before the vessel discharges. For this reason industrial samples are obtained mainly from the last throw of the trip. Offloading further damages the already partially-decomposed fish and one cannot sample from the conveyer belt because it would be impossible to weigh those fish. Directed sardine catch, on the other hand, is kept in a very good condition onboard on ice and good quality samples are easily obtained from the conveyor belt, whilst the vessel is discharging. Unfortunately it is seldom possible to establish which throw is being sampled. Field station data are available on Sybase from 1984 onwards. Ports sampled over the period include Lamberts Bay, Laaiplek, St. Helena Bay, Saldanha, Cape Town, Hout Bay, Kalk Bay, Hermanus, Gansbaai, Mossel Bay and Port Elizabeth.
- Observer samples: The observer program started in 1999 but was terminated in 2011. Onboard biological sampling was started only in 2001. Observer sampling results reflect an improvement on the field station data because samples are obtained from a known throw, all throws are sampled and the fish is always in a good condition. Unfortunately the length frequency samples have to be taken ashore for weighing and this gives rise to room for error. The data are stored in an Access database called CAPFISH.
- Industry cannery samples: As part of the quality process at the canneries, fish are also measured and weighed according to DAFF field station specification.

Data extraction from Sybase

- Catch data are extracted from Sybase as text (flat) files; *throw.csv* contains the skippers' data and *catch.csv* contains the inspectors' data.
- Field station data are extracted in the same manner; *spcomp*.csv contains the species composition data and *lfreq.csv* contains the length frequency data.

Data handling and evaluation

<u>DEFF data</u>

- Unfortunately there is no manual proof reading of all the data, except in cases where the number of throws is excessive (more than 10) and the trip duration is of an unrealistic duration (more than 3 days). Data validation is limited to electronic checking for noticeable mistakes.
- A duplicate dataset of *catch.csv* which is regularly updated by email is kept at Saldanha in an Access table. This means that the data are entered twice, but into separate databases and this allows for the comparison of the two data sets on a regular basis for differences and errors. It might appear unnecessary to keep two data sets, but this is the sole reason that the pelagic catch data remain representative of what was recorded by the scale monitors. From 2015 the entering of data into Access was stopped because this data in now obtained from Industry and used to verify the catches.
- The expected sample weights associated with the length frequency data in *lfreq.csv* are computed and samples that deviate more than 30% are flagged and checked against the raw data. If a flag results from a punch error then the data are corrected, but in the case of a sampling error the record is deleted from the data base.
- Suspect positions, for example areas outside the normal catch areas are checked against the raw data and, if necessary, corrected.

<u>Observer data</u>

- Limited manual proof reading of data.
- Only observer trips that match the commercial data for vessel name and date are used. Mismatched dates do occur, making it very difficult to establish whether a specific vessel carried an observer on a specific date. Therefore samples from such observer trips are ignored to prevent the inclusion of poor data. Only trips that do link can be used, because the scale monitor's species composition is used to determine the target species of the length frequency sample.
- The structure of the observer length frequency table is altered to make it compatible with the Sybase dataset.
- Only observer length frequencies whose predicted sample weights fall within the set range are used. Data with possible measurement errors or wrong species names are excluded.

Access programs

RLFdata.accdb (where the LFs are generated)

This program has links to the following data sets that is required for the computation.

1) Cannery data.accdb (sardine length frequency)
2) RSAP reference.accdb (data set with vessel detail and pool positions)

3) Capfish.accdb (if data from 2001 to 2011 is included)
4) Pel Catch (skipper data sets)

General program outline

- Catches are allocated to pool-area/week strata:
    1. Week: the throw date with the largest catch is used.
    2. Pool area: the existing 21 areas (see Figure A.2) are used, but from 1999 onwards area 21 was subdivided into areas 23 and 24, to accommodate the eastward fishing expansion. The throws within each landing are examined, and the throw with the greatest mass is used as the representative throw.
    3. Assign a target species to every catch. The species with the largest mass is defined as the dominant species in the landing.
- The length frequency samples are grouped by species and target species for the pool-area/week strata and summed.
- A new catch table with additional space for the allocated length frequencies is created.
- The length frequency table is searched and a frequency based on the species, target species, week and pool area criteria are assigned to the catch table.
- In the event of catches not being represented by an appropriate sample, the pool-area/week will be expanded to include surrounding areas and weeks. Stratum expansion continues alternately by week and pool until an appropriate frequency is located.
- If no appropriate sample is found then the average sample for the month is applied. Where no sample for the month exits in the case of anchovy, the length frequency is estimated using the length frequency of a former month as detailed in the text. Where no sample for the month exists in the case of sardine, the previous month is used. Catches of each species and the length frequencies are summed by month over larger user specified areas.
- The length frequencies are exported as Excel files in numbers per length group.

The user specified areas that are used are:

1. Areas 1-6: North of Cape Columbine
2. Areas 7-12: Cape Columbine to Cape Point
3. Areas 13-20: Cape Point to Cape Infanta
4. Area 23: Cape Infanta to Plettenberg Bay
5. Area 24: East of Plettenberg Bay

In 2007, the border between area 23 and 24 was shifted slightly west to 24 degrees east (Tsitsikama), although this made little difference in practice since catches between 23 and 24 were small.

Although the LFs are summarized according to different areas, the allocation process is still based on the original pool areas, with the exception of those cases where pool areas were split by the new borders.

Program changes

In January 2007 four changes were made to the process above:

- The observer length frequencies were included.

- To prevent juvenile sardine frequencies from being allocated to adult sardine catches, the species was separated into directed and by catch for allocation purposes. This is applicable only when sardine is landed as a by catch with anchovy. Sardine by catch with anchovy is mainly juvenile fish whereas by catch with round herring it is mostly adult fish.
- Noticeable error in the LF results when the field station catch composition data are used to identify the target species of the length frequency sample, and these composition data differ from those of the scale monitor. Because the field station data are not proofread, and given the inclusion of the observer length frequencies (they also need a target species to be identified), it was decided to standardize on the scale monitors species composition as the only source.
- Missing skipper data (catch area) are catered for. This occurs when the skipper fails to hand in a trip sheet. Currently this is not a major problem but it did happen in the 1980s and 1990s. Where the *catch.csv* file does not have a related record in the *throw.csv* file, the program will search for the most likely catch position, based on the catch type of the other vessels for the same date.
- From 2012 the cannery length frequencies are included.

The first change leads to enhanced coverage, especially in the case of industrial fish, i.e. anchovy that are poorly sampled by the field stations. The last three changes were implemented to prevent errors caused by bad data or poor sampling coverage. This can typically be seen in a LF plot as an improbable peak at a certain length group.

In March 2007 an additional change was implemented. Towards the end of the year sporadic landings can be overlooked, because it is not cost effective to continue extensive sampling. These landings are generally small but it is still necessary to allocate a size to the fish. In the past the annual LF average was used, but it was felt that it is better to allocate the LF from the adjacent month. The LFs are first stratified by area and species type, but where no match is found the requirements for matching area and target species are removed alternatively until a match is found.

Even though throws in multiple pool areas during a single trip do occur, only the catch area for the biggest throw is selected. This is done in order to keep continuity with the old sample allocation method. A change that could be considered would be to allocate a sample to every throw as opposed to every trip. The scale monitor samples at regular intervals and discrete throws are not sampled. However, if one assumes the species composition of the throws are uniform, then the catch per throw can be calculated, by proportionally applying the species composition to individual throws. Observer sampling is ideally suited for this approach, because every throw is sampled, but greater sampling coverage and matched skipper throws are required.

Sampling coverage

Optimum sample size and sampling coverage can be determined only by using a suitable statistical study, and one can therefore only speculate on the sample size required. Logistic constraints have necessitated a random stratified sampling method, and the grouping of catches and samples on a week/pool-area basis has been adopted since electronic data processing began. Both the sampling and the length frequency approaches are arguably the most suitable considering the fishing strategy and the available data. The percentage coverage per stratum is readily quantified, and the first level pool-area/week coverage could possibly be used as an index of sampling coverage. 100 percent coverage is not attainable because of financial and logistic constraints, and it is more than likely unnecessary. From Figure A.1 it appears that 80 percent coverage is attainable.

Many factors influence the relationship between the number of samples taken and the coverage obtained, but in general more samples will lead to better coverage. In earlier years field stations were well manned and more samples were taken than presently. The Observer program was introduced in 2000 and this improved sampling and as a result field station sampling was reduced. However, when the program was terminated in 2011 the field station coverage was not adjusted to earlier levels. This poor coverage can be seen see as the low values on the graph in Figure A.1. The fisheries cannery data (used since 2012) is necessary to maintain directed sardine sampling levels.

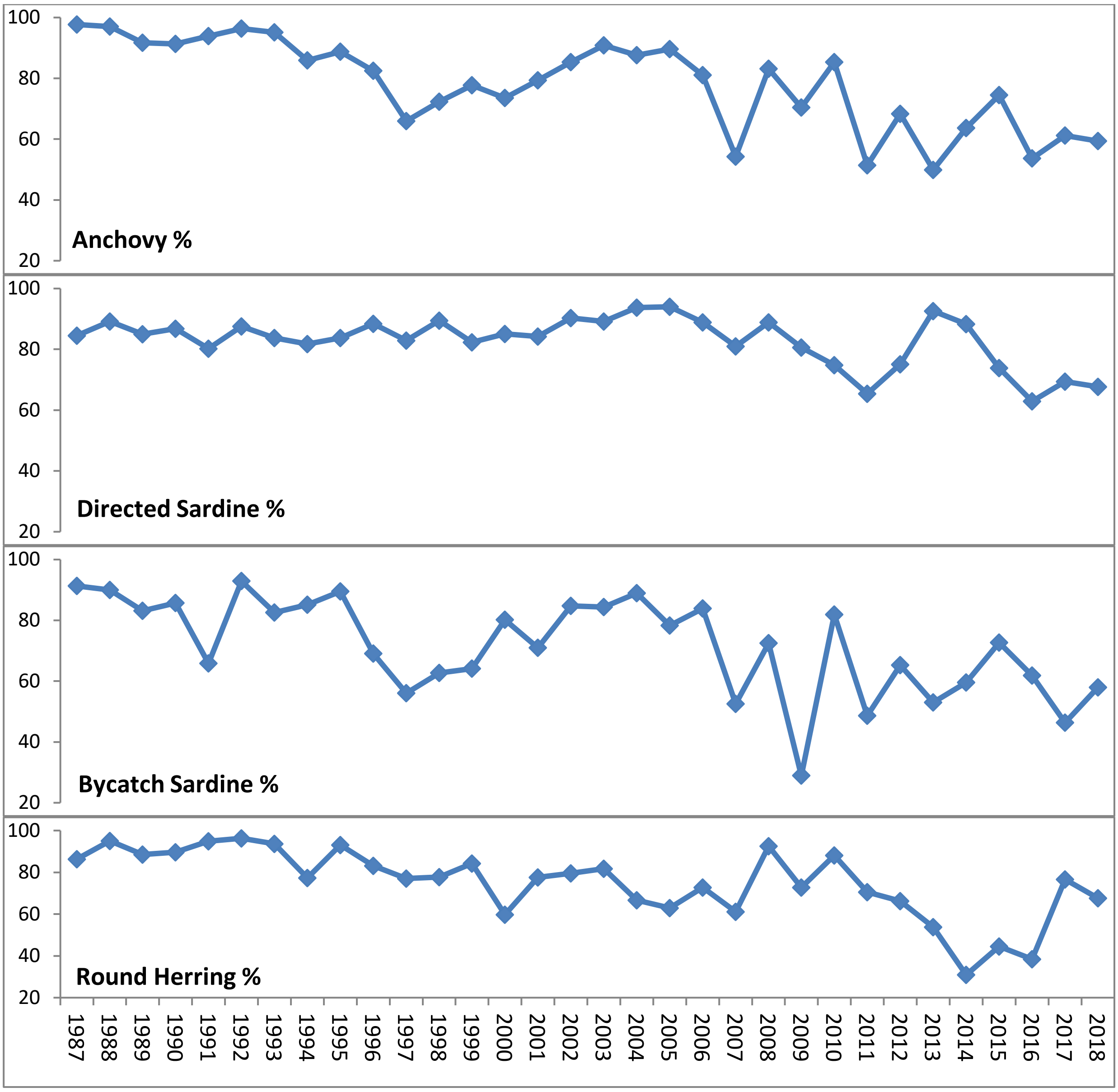

Figure A.1. Sampling coverage obtained on a first level pool-area/week.

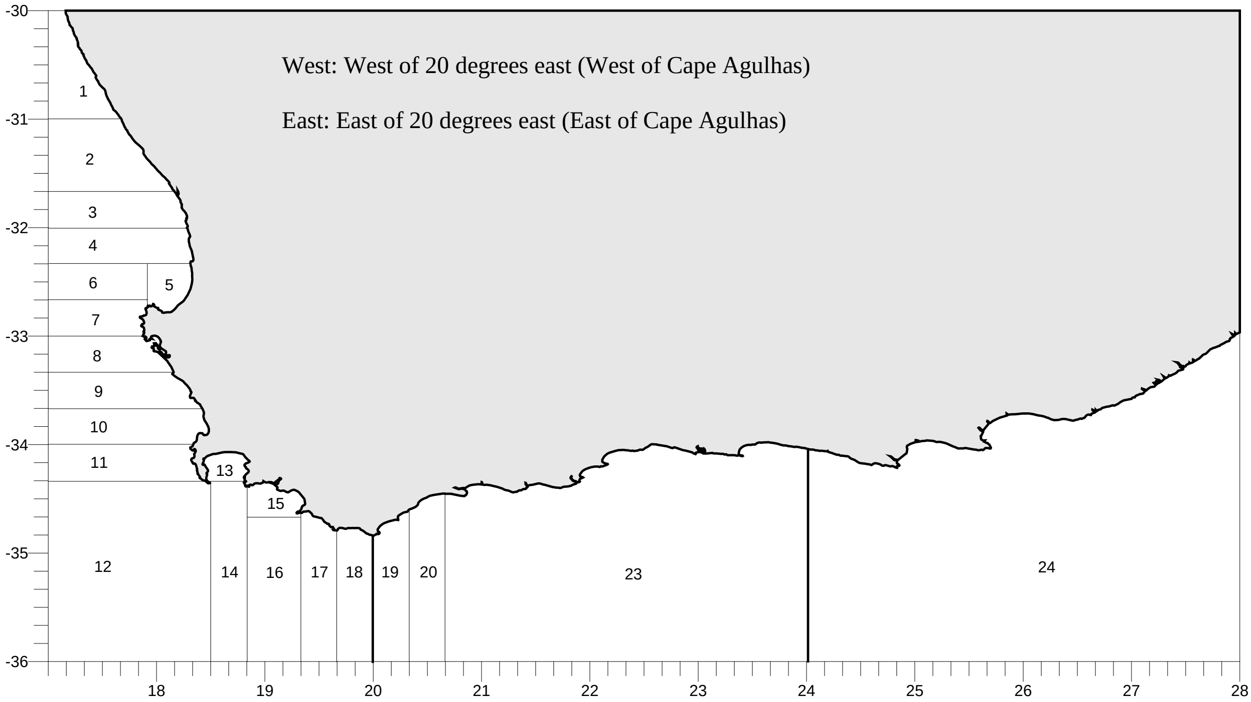

Figure A.2. The pool areas that are used for sample allocation.

Appendix B: Methods Used to Calculate Recruit Biomass

Two different methods are used to calculate recruit biomass. The first has been used since the start of the time series and is used to calculate recruit numbers, while the second was devised as a method to estimate CVs of recruit-only biomass. The biomasses differ between the methods due to the differences in the way the densities are weighted.

Method 1

This method, designed by Ian Hampton and Beatriz Roel, has been used since the start of the time series and calculates recruit biomass, number of recruits (less than a certain cut-off length) and a recruit mean weight:

1) The acoustic biomass per stratum (of adults and recruits) is calculated using the Jolly and Hampton method (i.e., each interval is weighted by interval length and a mean density per transect is calculated. Each transect is again weighted by its length to get a mean density per stratum).

2) Each acoustic interval has been linked to a particular grid reference (trawl sample) which was used to scale the acoustic energy to density. The trawl sample has a length frequency (LF) and associated length frequency mass (LFMASS). This LF and LFMASS include both adults and recruits as it is impossible at this stage (at sea) to know what the cut-off length for a recruit is. The LFMASS is the total weight of the LF sample (the combined weight of all fish of a particular species measured for the LF distribution).

3) For each interval, the acoustic density is multiplied by the interval length. This weighted interval density is then summed over all intervals for each grid reference, per stratum and per species to give an acoustic weighting to each grid reference, $w_{GR}(grid, stratum, species)$.

4) The weighted grid reference is then summed over all grid references for each stratum and species to give a weighted grid reference per stratum for each species, $w_{GR}(stratum, species)$.

5) For each length class of each grid reference, calculate a Trawl WF (trawl weighting factor) $= w_{GR}(grid, stratum, species)/LFMASS$. This converts the acoustic weighting (in terms of mass) into a factor in terms of numbers.

6) The length frequency (LF) is then weighted by this Trawl WF and summed for each length class to give a weighting to each length class (Lgroup) for each stratum for each species sum(number*trawl WF), $WLF(Lgroup, stratum, species)$.

7) $WLF(Lgroup, stratum, species)$ is then scaled to the biomass of the stratum: $BLF(Lgroup, stratum, species) = [WLF(Lgroup, stratum, species) * Biomass(stratum, species)]/\sum w_{GR}(stratum, species)$.

8) BLF is then summed across all strata for each species to give a final length frequency per species for the survey (this is done separately up to Cape Infanta and for the whole survey).

9) For each species an age/length matrix is then generated using a cut-off length for recruits.

10) The proportion in each length class is multiplied by BLF to get the total number of 0-year olds (recruits) and the total number of 1-year olds (adults). This is again done separately as far as Cape Infanta and for the whole survey. The number of fish in each length class is then multiplied by a length weight regression to get an estimated weight (in grams) for each length class, where $w = 0.00924 \times Lgroup^{3.046}$ for anchovy and $w = 0.0096 \times Lgroup^{3.075}$ for sardine.

11) The numbers and weights are then summed across all length classes for each species to give total number of 0-year-olds, $N_{tot,0}$, and 1-year-olds, $N_{tot,1}$, and total weight of 0-year-olds, $W_{tot,0}$, and 1-year-olds, $W_{tot,1}$.

12) The mean weight of 0-year-olds and 1-year-olds is then calculated by $MW_a = \left(w_{tot,a}/1000000\right)/N_{tot,a}$. The calculated biomass is then $B_{calc} = MW_0 \times N_{tot,0} + MW_1 \times N_{tot,1}$ and should be close to the acoustic biomass, $B_{acoustic}$. B_{calc} and $B_{acoustic}$ are not always identical because in some years the fish are heavier/lighter than that predicted by the length weight regression. The mean weight of recruits and 1–year-olds is weighted by the ratio of the calculated to actual acoustic biomass to get a corrected mean weight: $CMW_a = MW_a \times B_{acoustic}/B_{calc}$.

Method 2

This method was devised to map recruit only density rather than the density of combined adults and recruits. In summary the density in each interval is multiplied by the proportion of recruits in that interval to get a recruit only density. The proportion of recruits in each interval is obtained by calculating the proportion of acoustic energy backscattered by recruits only, based on the length frequency that each interval has been assigned and a cut-off length:

1) For each trawl (grid) the acoustic back scattering for each length class is calculated for each species and multiplied by the number of fish in that length class (basically applying the species specific target strength relationship to the length class (L_t)):

$$BS = \begin{cases} 10^{0.1\times -21.12} \times L_t^{-12.15/10} \times N & if\ Sp = 1 \\ 10^{0.1\times -13.21} \times L_t^{-14.9/10} \times N & if\ Sp = 2\ or\ 5 \\ 10^{0.1\times -7.75} \times L_t^{-15.44/10} \times N & if\ Sp = 3\ or\ 4 \end{cases}$$

where *Sp* 1 = anchovy, *Sp* 2 = sardine, *Sp* 3 = horse mackerel, *Sp* 4 = mackerel and *Sp* 5 = round herring.

2) The backscattering (*BS*) is summed for each species for each trawl to give a total backscatter for each grid, BS_{tot}.

3) The backscattering due to recruits, BS_{rec}, is then calculating by summing *BS* for only the length classes less than the cut-off length for each species for each trawl. The cut-off length is obtained from the modal progression analysis after using Method 1 above to weight the length frequency of the entire survey.

4) The proportion of recruits in each trawl is then calculated by BS_{rec}/BS_{tot}.

5) This proportion is then multiplied by the original interval density (of recruits and adults) to obtain the recruit only density (for all years).

6) This recruit only density is used in the regressions of capped to uncapped data in order to estimate (using the Jolly and Hampton weighting procedure) the uncapped recruit only biomass prior to 1997 together with a CV.

Appendix C. Extrapolation of recruit numbers to Cape Infanta in the years for which the survey only reached Cape Agulhas

The time series of sardine and anchovy recruits used in assessments and to set the final anchovy TAC and sardine TAB in June each year are based on the surveyed area west of Cape Infanta. In some years, the survey did not cover the full area eastwards to Cape Infanta. Between 1985 and 1990, the survey was regularly terminated at Cape Agulhas. In 2011, although the survey was planned to extend eastwards of Cape Infanta, the survey only covered the area west of Cape Agulhas as damage to the survey vessel resulted in an early end to the survey. This Appendix uses the same approach as in de Moor and Butterworth (2011) to extrapolate the survey estimate of recruit numbers and associated variance in years when only the area up to Cape Agulhas was surveyed, but based now on an updated and extended time series of data.

Method

Table C.1 lists the recruit numbers west of Cape Agulhas (strata A-E in recent years) and between Cape Agulhas and Cape Infanta (stratum F in recent years) for years for which these data can be extracted. The ratio of recruits between Cape Agulhas and Cape Infanta to those west of Cape Agulhas is computed as r_y. The recruits between Cape Agulhas and Cape Infanta can then be estimated using the average of these proportions, $\bar{r}$, i.e. $N_{stratumF} = \bar{r}N_{strataA-E}$.

The variance of the extrapolated estimate west of Cape Infanta is then estimated as follows:

$$var(N_{stratumA-F}) = var\big((1+\bar{r})N_{strataA-E}\big) = var(1+\bar{r})(N_{strataA-E})^2 + (1+\bar{r})^2 var(N_{strataA-E})$$

where

$$var(1+\bar{r}) = var(\bar{r}) = \frac{1}{n-1}\sum_y \left(r_y - \bar{r}\right)^2$$

and

$var(N_{strataA-E}) = (N_{strataA-E}/CV(N_{strataA-E}))^2$. Although the CV is calculated from the biomass rather than the number of recruits west of Cape Agulhas, this is assumed to be an adequate assumption for these purposes.

Results and Recommendations

The average proportion of recruits between Cape Agulhas and Cape Infanta to that west of Cape Agulhas over the years 1991 to 1995, 1998 and 1999 is 0.02 for anchovy and 0.06 for sardine (Table C.1). However, the proportion of sardine recruits between Cape Agulhas and Cape Infanta in 1999 was exceptionally high. Treating this point as an outlier results in an average of 0.004. These low proportions correspond with the previously held assumption of there being few recruits between Cape Agulhas and Cape Infanta historically. While one might argue no extrapolation for these early years is required under the perception of a regime shift in the early 2000s, to maintain consistency with the 2011 adjustment (see below), <u>it is recommended that the anchovy and sardine recruit numbers for 1985 are multiplied by 1.02 and 1.004, respectively (see Table C.1)</u>. The CVs of these estimates have all decreased marginally, but to three decimal places they remain the same.

The average proportion of recruits between Cape Agulhas and Cape Infanta to that west of Cape Agulhas is 0.01 for anchovy and 0.52 for sardine over the years 2002 to 2019, excluding 2011 when the survey ended at Cape Agulhas and 2018 when there was no survey. <u>It is recommended that the 2011 survey estimate of anchovy recruit numbers be increased from 99.703 billion recruits (with a CV of 0.286), reflecting the area west of Cape Agulhas, to 100.592 billion recruits (with a CV of 0.286), reflecting the area west of Cape Infanta</u> (Table C.1). The proportion of sardine recruits between Cape Agulhas and Cape Infanta in 2015 and 2019 was exceptionally high. Treating these points as outliers results in an average proportion of sardine recruits between Cape Agulhas and Cape Infanta of 0.03. It is recommended that the 2011 survey estimate of sardine recruit numbers be increased from 5.624 billion recruits (with a CV of 0.396), reflecting the area west of Cape Agulhas, to 5.831 billion recruits (with a CV of 0.396), reflecting the area west of Cape Infanta (Table C.1). The CVs of these estimates have decreased marginally, but to three decimal places they remain the same.

Table C.1. Recruit numbers, ratios and summary statistics estimated from surveys. The recruit numbers between Cape Agulhas and Cape Infanta, given in **bold**, have been extrapolated using the recommendations in the text. Note that numbers are quoted in billions (10^9).

	Anchovy			Sardine		
	Recruit numbers west of Cape Agulhas (strata A-E)	Recruit numbers between Cape Agulhas and Cape Infanta (stratum F)	Ratio F:A-E	Recruit numbers west of Cape Agulhas (strata A-E)	Recruit numbers between Cape Agulhas and Cape Infanta (stratum F)	Ratio F:A-E
1985	83.454	**1.984**		3.592	**0.014**	
1986	142.640	**3.311**		3.691	**0.014**	
1987	127.424	**2.958**		7.380	**0.029**	
1988	132.106	**3.067**		0.440	**0.002**	
1989	33.920	**0.787**		2.137	**0.008**	
1990	52.362	**1.216**		2.502	**0.010**	
1991	112.836	0.749	0.01	1.909	0.006	0.00
1992	87.083	6.598	0.08	5.614	0.019	0.00
1993	109.024	6.034	0.06	15.200	0.039	0.00
1994	30.401	0.153	0.01	2.642	0.013	0.00
1995	110.419	0.020	0.00	25.382	0.006	0.00
1996	25.771[13]		-	3.204[13]		-
1997	90.210[13]		-	36.856[13]		-
1998	136.458	0.060	0.00	10.616	0.100	0.01
1999	194.750	4.477	0.02	7.298	3.080	0.42
2000	624.675[13]		-	20.002[13]		-
2001	627.200[13]		-	60.065[13]		-
2002	496.720	23.693	0.05	45.786	3.367	0.07
2003	430.247	0.062	0.00	33.406	3.042	0.09
2004	236.240	2.329	0.01	4.074	0.015	0.00
2005	166.266	0.090	0.00	2.670	0.188	0.07
2006	114.263	0.217	0.00	9.463	0.043	0.00
2007	481.401	0.182	0.00	2.983	0.012	0.00
2008	568.143	5.286	0.01	4.074	0.016	0.00
2009	292.009	12.398	0.04	9.149	0.140	0.02
2010	300.007	0.441	0.00	35.117	0.453	0.01
2011	99.703	**0.889**		5.624	**0.207**	
2012	128.900	0.397	0.00	6.963	1.023	0.15
2013	324.216	0.582	0.00	12.581	0.006	0.00
2014	185.330	1.934	0.01	1.959	0.026	0.01
2015	217.010	0.159	0.00	0.731	5.527	7.56
2016	92.583	0.030	0.00	0.804	0.007	0.01
2017	819.990	10.211	0.01	6.730	0.450	0.07
2018		No survey			No survey	
2019	268.573	1.749	0.01	2.821	0.719	0.25
Average 1991-1995,98,99			0.02			0.06[14]
Average 2002-2010,2012-2017,2019			0.01			0.52[15]

[13] Strata E and F were combined in these years.
[14] 0.00 if 1999 is excluded.
[15] 0.05 if 2015 is excluded. 0.04 if 2015 and 2019 are excluded.