Exploring options for spatially disaggregated directed sardine catch under OMP-14

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Background

At the March 2014 Small Pelagic Scientific Working Group (SPSWG) meeting it was agreed that the most appropriate way-forward in terms of management of the sardine and anchovy pelagic fishery would be to finalise an Operational Management Procedure (OMP) as soon as possible, based on an extension to Interim OMP-13v3, with guidelines for some spatial disaggregation of directed sardine catch. This document considers alternative predictors of past splits of the directed sardine catch west and east of Cape Agulhas and proposes a way forward to develop a rule that could be used to advise on the split west and east of Cape Agulhas of the directed sardine TAC under OMP-14.

Predictors of past proportions of sardine catch taken west of Cape Agulhas

In all these models, the proportion of catch west of Cape Agulhas is the predicted variable which is compared with the observations. Figure 1 shows the historic time series of these observed proportions, together with the proportion of survey estimated sardine biomass west of Cape Agulhas in the previous November. Given changes in industry over time (e.g. changes in rights holders, processing plants), models are tested only on data from the past 10 years. The following models have been evaluated for their ability to predict the proportion of sardine catch west of Cape Agulhas in year y:

i) **Survey**: the proportion of survey estimated biomass west of Cape Agulhas in y-1 only.

ii) **Avg 2 Surveys**: the average of the proportion of survey estimated biomass west of Cape Agulhas in y-1 and y-2.

iii) **Avg 3 Surveys**: the average of the proportion of survey estimated biomass west of Cape Agulhas in y-1, y-2 and y-3.

iv) **Weight 3 Surveys**: the weighted average (with weights fixed on input) of the proportion of survey estimated biomass west of Cape Agulhas in y-1, y-2 and y-3, with greater weights given to more recent years.

v) **Est Weight 3 Surveys**: the weighted average (with weights estimated to give optimal performance) of the proportion of survey estimated biomass west of Cape Agulhas in y-1, y-2 and y-3.

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vi) **Weight 5 Surveys**: the weighted average (with weights fixed on input) of the proportion of survey estimated biomass west of Cape Agulhas in y-1, y-2, y-3, y-4 and y-5, with greater weights given to more recent years.

vii) **Avg 2 Surveys & Catch**: the average of the proportion of survey estimated biomass west of Cape Agulhas in y-1 and y-2, and the average of the proportion of catch west of Cape Agulhas in y-1 and y-2, with greater weight given to the survey data.

The model equations are listed in Table 1, and the parameters are estimated by minimising a simple sum of squares. The variance for each model is calculated as follows:

$$Var = \frac{1}{(y_n - y_1 + 1) - i} \sum_{y=y1}^{yn} \left(prop(\hat{C}_y) - prop(C_y) \right)^2 \tag{1}$$

where $prop(\hat{C}_y)$ denotes the predicted proportion of sardine catch west of Cape Agulhas in year y (Table 1), and $prop(C_y)$ denotes the historic observed proportion of sardine catch west of Cape Agulhas in year y.

Predictors of past proportions of November survey estimates of sardine abundance west of Cape Agulhas

The same models i) to vii) (Table 1) are used, but the proportion of the forthcoming year's November survey estimate of sardine abundance west of Cape Agulhas is the predicted variable to be compared with the observations. The parameters are again estimated by minimising a simple sum of squares. The variance for each model is calculated as follows:

$$Var = \frac{1}{(y_n - y_1 + 1) - i} \sum_{y=y1}^{yn} \left(prop(\hat{B}_y) - prop(B_y) \right)^2 \tag{2}$$

where $prop(\hat{B}_y)$ denotes the predicted proportion of sardine surveyed west of Cape Agulhas in November of year y (Table 1), and $prop(B_y)$ denotes the historic observed proportion of sardine catch west of Cape Agulhas in year y.

Results and discussion of predictors of past proportions

The models were fit to observed proportions from the past ten years and from the past six years; where the latter was chosen to exclude the period of peak sardine catches. However note that the years for which survey and catch data are used extend earlier than the past ten or six years – up to five years prior to 2004 and 2008, respectively. The model predicted proportions of sardine catch west of Cape Agulhas are compared to those observed in Figure 2, while the model predicted proportions of November survey abundance west of Cape Agulhas are compared to those observed in Figure 3.

When predicting the proportion of sardine catch west of Cape Agulhas, the model based on a weighted average of the past five survey estimated proportions of sardine biomass west of Cape Agulhas ("Weight 5 Surveys"), with a greater weight given to more recent surveys, has the lowest variance of all models based on survey data alone (Table 2). This is closely followed by alternatives based on the past two or three surveys. The model based on both the survey and catch data from the previous two years ("Avg 2 Survey & Catch") has the lowest overall variance. All alternatives have a substantially lower variance than the option i) based on the survey estimate in the previous year only. In all models based on survey data alone, the additive bias is estimated between 0.20-0.25, while for the model based on both past survey and catch data the additive bias estimated is lower (unsurprisingly as the past catch split is "biased" in relation to the survey split) (Table 2).

When predicting the proportion of November survey estimated sardine abundance west of Cape Agulhas, again the model "Weight 5 Surveys" has the lowest variance of all models (Table 3), and once again this is substantially lower than option i) based on the survey estimate in the previous year only. However, this variance is much higher than that obtained from models predicting the proportion of sardine catch west of Cape Agulhas (Tables 2 and 3). The additive bias estimated is larger over the shorter time period (0.09-0.14 compared to 0.04-0.06) due to the greater contribution of the recent upward trend in the survey proportion west of Cape Agulhas to the model fit.

In summary, therefore, we are able to better predict (lower variance) the proportion of catch west of Cape Agulhas than the proportion of survey estimated biomass west of Cape Agulhas. In all models, a non-negligible additive bias is required to fit the data; the bias being much bigger than the standard deviation when predicting the proportion of catch west of Cape Agulhas, but much smaller than the standard deviation when predicting the proportion of survey estimated biomass west of Cape Agulhas (Tables 2 and 3).

This section has identified some models able to predict the proportion of catch (or November survey biomass) west of Cape Agulhas with a best standard deviation of less than 0.07. These catch proportions reflect what has occurred in the absence of any directive regarding spatial management requirements for the sardine TAC, but provide information on the magnitude of the bias between the catch and the survey proportions, and on how much flexibility about recommended catch proportions might be appropriate, given the level of precision with which the proportion can be estimated. The next step in the process is to move from models which can predict the proportion of catch west of Cape Agulhas under such non-restrictive circumstances to models which can recommend appropriate proportions of catch to be taken west of Cape Agulhas each year.

A note must be made about the limited time for which these models can be used. The additive bias estimated in these models means that is it possible for proportions greater than 1 to be predicted (or even less than 1 when also taking a precision-related range into account). Thus, for example, if the current upward trend in the proportion of the survey west of Agulhas continues, these models would soon produce unrealistic results.

Recommendations for proportions of sardine catch to be taken west of Cape Agulhas under OMP-14

In order to provide advice on a rule to be used to recommend the proportional split of the directed sardine TAC west and east of Cape Agulhas, the SPSWG first needs to agree on what the median annual proportional split in sardine catch should ideally be based (i.e. ignoring any variability about the proportional split to be recommended). It should be noted that given stock structure uncertainty, the management objective generally adopted is to split the catch by area in the same proportions as the split of the resource abundance by area. In the absence of such advice, we present a way forward based on four example scenarios.

The proportion of sardine catch west of Cape Agulhas in year y should be based on:

a) The proportion of sardine biomass estimated to be west of Cape Agulhas in the November *y*-1 survey. Thus the forthcoming catch should reflect the distribution of the sardine during the preceding November.
b) The average of the proportions of sardine biomass estimated to be west of Cape Agulhas in the surveys in Novembers *y*-1 and *y*-2. This may have the advantage over option a) in smoothing out any large, but potentially temporary changes in the survey distributions.
c) The average of the proportion of survey estimated biomass west of Cape Agulhas in *y*-1 and *y*-2, and the average of the proportion of catch west of Cape Agulhas in *y*-1 and *y*-2, with greater weight given to the survey data. This was the model for past proportions of catch west of Cape Agulhas that was best able to follow the trends in proportions (smallest variance). The inclusion of historic catch in the model means that it is making some allowance for industry's past socio-economic preferences.
d) The average of the proportions of sardine biomass west of Cape Agulhas in the surveys in Novembers *y*-1 (as observed) and *y* (as best predicted). Thus the forthcoming catch should reflect the average distribution of the sardine during the catch period by averaging the values at its start and finish.

The first three models upon which to base a recommendation depend solely on observed data. As a means to gauge how close the actual catch split has been compared to these recommendations, the "recommended" proportion of catch west of Cape Agulhas from each of these models are compared to the observed proportions in Figure 5 for recent years. The "recommended" proportions are plotted with error bars where the standard error has been calculated from the variance of the observed survey data (see Appendix), with observed catch assumed to be known exactly. Model d) requires a prediction of the proportion of sardine west of Cape Agulhas in the forthcoming November *y*. Due to the changing survey proportion trend over time, it was decided to use models fit to data for 2008-2013 only. Although "Weight 5 Surveys" is the best model to predict the forthcoming survey's proportional split (Table 3), the model "Avg 2 surveys" was chosen for simplicity. Figure 4 shows the difference between using these two models to predict the proportion of survey estimated biomass west of Cape Agulhas in Novembers 2008 to 2013. The error bars plotted in Figure 5d are thus based on half the variance of the survey observation for November *y*-1 and half the variance of the model prediction for the "Avg 2 surveys" model. These proportions and errors are also listed together with CVs in Table 4.

The observed proportion of catch west of Cape Agulhas has been consistently higher than that "recommended" by the four example models a)-d), with the observed proportion frequently being greater than one standard error above the "ideal" proportion, and a greater variance evidenced for model d) compared to models a)-c) (Figure 5, Table 4). Thus use of any of these models as the basis for a recommendation implies that the industry would be asked to shift their catches further to the east than has recently been the case.

In summary, depending on the basis chosen by the SPSWG on which to recommend a median proportion of sardine catch west of Cape Agulhas (i.e. models a) – d) or other alternative), some shift in industry effort will likely be required in order to reach the likely acceptable error bounds about the median recommended proportion. In addition to advising on a basis from which to recommend the desired proportional split of the catch, the SPSWG must also advise on an acceptable error about such a recommendation. Figure 5 has shown, for example, ±1 standard error of the annual observations[1] used in the model to provide the recommended proportion. The allowable ranges thus differ between models due to the difference in CVs; the greatest range being for model d). The SPSWG needs to further discuss whether it is realistic to request industry to achieve a split within, say, +- 1 SE bounds of the recommended proportions, or whether some further tolerance ("bias") should be allowed during the short term (during OMP-14 application).

Thus the recommendation for the proportion of directed sardine west of Cape Agulhas in year *y* under OMP-14 will be

$$p(\text{ideal}) \pm \text{error} + \text{bias}$$

[1] In the case of model d) a predictive model variance, constant for all years, is also used.

where p(ideal) denotes the "ideal" best estimate for the proportion of the catch west of Cape Agulhas calculated on the basis determined by the SPSWG (e.g. models a)-d) above).

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Appendix

Given the function $C = f(A, B)$, and assuming no covariance between variables A and B, i.e. $\mathrm{cov}(A, B) = 0$, the delta method gives:

$$Var(C) = Var(A)\left(\frac{\partial f}{\partial A}\right)^2 + Var(B)\left(\frac{\partial f}{\partial B}\right)^2 . \tag{A.1}$$

Defining the survey estimate of biomass west of Cape Agulhas to be A and that east of Cape Agulhas to be B, the proportion of the survey biomass west of Cape Agulhas is given by $C = \frac{A}{A+B}$. Then, from equation (A.1) the variance of the proportion of the survey biomass west of Cape Agulhas is given by (Table A.1):

$$Var(C) = \frac{Var(A)B \;\; + Var(B)A^2}{(A+B)^4} .$$

Table A.1. The November hydroacoustic survey biomass (in tons) west and east of Cape Agulhas and the proportion of this biomass west of Cape Agulhas, with associated variances

	West of Cape Agulhas		East of Cape Agulhas		West of Cape Agulhas		
	Biomass	Variance	Biomass	Variance	Proportion	Variance	Std Error
2008	211871	12519357620	172209	13781174745	0.55	0.045	0.21
2009	262175	5587405037	239400	12895870987	0.52	0.019	0.14
2010	309465	10329938470	198927	3896301584	0.61	0.012	0.11
2011	182825	1170417197	854235	58356961623	0.18	0.002	0.05
2012	186109	9241456024	158945	4901453096	0.54	0.028	0.17
2013	654796	81319146923	196758	7568293930	0.77	0.012	0.11

Table 1. The models used to predict the proportion of sardine catch west of Cape Agulhas in year *y*, $prop(\hat{C}_y)$, or the proportion of November survey estimated sardine abundance west of Cape Agulhas in year *y*, $prop(\hat{B}_y)$, based on historic survey estimates of sardine abundance, $prop(B_y)$, and observed proportions of catch west of Cape Agulhas, $prop(C_y)$. In all models an additive bias, q, is estimated.

Alternative	Predictor $prop(\hat{C}_y)$ or $prop(\hat{B}_y)$	Estimated Parameters
Survey	$= prop(B_{y-1}) + q$	q
Avg 2 Surveys	$= 0.5\,prop(B_{y-1}) + 0.5\,prop(B_{y-2}) + q$	q
Avg 3 Surveys	$= 0.33\,prop(B_{y-1}) + 0.33\,prop(B_{y-2}) + 0.33\,prop(B_{y-3}) + q$	q
Weight 3 Surveys	$= 0.5\,prop(B_{y-1}) + 0.33\,prop(B_{y-2}) + 0.17\,prop(B_{y-3}) + q$	q
Est Weight 3 Surveys	$= a \times prop(B_{y-1}) + b \times prop(B_{y-2}) + (1-a-b) \times prop(B_{y-3}) + q$	a, b, q
Weight 5 Surveys	$= 0.5 prop(B_{y-1}) + 0.33 prop(B_{y-2}) + 0.17 prop(B_{y-3}) + 0.17 prop(B_{y-3}) + 0.17 prop(B_{y-3}) + q$	q
Avg 2 Surveys & Catch	$= 0.6 \times (0.5 prop(B_{y-1}) + 0.5 prop(B_{y-2})) + 0.4 \times (0.5 prop(C_{y-1}) + 0.5 prop(C_{y-2})) + q$	q

Table 2. The variance (Equation 1) and corresponding standard error (SE) obtained from the alternative model fits to proportions of directed sardine catch west of Cape Agulhas. The **bolded** values are for the minimum variance.

	Fitting to data from 2004-2013					Fitting to data from 2008-2013				
Alternative	a	b	q	Variance	SE	a	b	q	Variance	SE
Survey			0.23	0.027	0.165			0.20	0.038	0.195
Avg 2 Surveys			0.24	0.012	0.109			0.22	**0.007**	0.085
Avg 3 Surveys			0.24	0.012	0.111			0.23	**0.007**	0.086
Weight 3 Surveys			0.24	0.012	0.108			0.22	0.008	0.092
Est Weight 3 Surveys	0.43	0.43	0.24	0.014	0.120	0.29	0.54	0.23	0.008	0.090
Weight 5 Surveys			0.25	0.011	0.103			0.25	0.007	0.082
Avg 2 Surveys & Catch			0.14	**0.001**	**0.030**			0.16	**0.004**	**0.065**

Table 3. The variance (Equation 2) and corresponding standard error (SE) obtained from the alternative model fits to proportions of November survey estimated sardine abundance west of Cape Agulhas. The **bolded** values are for the minimum variance.

	Fitting to data from 2004-2013					Fitting to data from 2008-2013				
Alternative	a	b	q	Variance	SE	a	b	q	Variance	SE
Survey			0.04	0.064	0.253			0.09	0.087	0.296
Avg 2 Surveys			0.05	0.060	0.246			0.11	0.077	0.278
Avg 3 Surveys			0.05	0.058	0.241			0.13	0.073	0.271
Weight 3 Surveys			0.05	0.057	0.238			0.12	0.073	0.270
Est Weight 3 Surveys	0.57	0.15	0.05	0.071	0.267	0.47	0.24	0.12	0.120	0.347
Weight 5 Surveys			0.06	**0.053**	**0.229**			0.14	**0.059**	**0.243**
Avg 2 Surveys & Catch			0.05	0.060	0.246			0.11	0.077	0.278

Table 4. The observed and model recommended proportion of sardine catch west of Cape Agulhas in 2008 to 2014 (excluding bias in the model recommended proportion). The recommended values are shown with ±1 standard error in square brackets and a CV in percentages. The recommended sardine catch proportion in year y is estimated by a) the proportion of survey estimated biomass west of Cape Agulhas in November y-1, b) the average of the proportions of survey estimated biomass west of Cape Agulhas in Novembers y-1 and y-2, c) the average of the proportion of survey estimated biomass west of Cape Agulhas in Novembers y-1 and y-2 and the proportion of catch west of Cape Agulhas in y-1 and y-2, with greater weight given to the survey data, and d) the average of the proportions of survey biomass west of Cape Agulhas in November y-1 (estimated in the survey) and November y, where the latter proportion is predicted by model "Avg 2 surveys".

Year	Observed	Last survey	Avg 2 surveys	Avg 2 surveys & catch	Avg last and next surveys
2008	0.49	0.22 [0.11,0.34] 51%	0.24 [0.16,0.32] 34%	0.30 [0.20,0.40] 32%	0.30 [0.15,0.45] 50%
2009	0.62	0.55 [0.34,0.76] 39%	0.39 [0.27,0.51] 31%	0.41 [0.26,0.55] 35%	0.36 [0.19,0.54] 48%
2010	0.70	0.52 [0.39,0.66] 26%	0.54 [0.41,0.66] 24%	0.54 [0.39,0.70] 28%	0.60 [0.45,0.76] 26%
2011	0.65	0.61 [0.50,0.72] 18%	0.57 [0.48,0.65] 15%	0.60 [0.50,0.71] 17%	0.60 [0.45,0.75] 25%
2012	0.73	0.18 [0.13,0.23] 28%	0.39 [0.33,0.45] 15%	0.51 [0.44,0.58] 14%	0.56 [0.42,0.70] 25%
2013	0.60	0.54 [0.37,0.71] 31%	0.36 [0.27,0.45] 25%	0.49 [0.39,0.60] 21%	0.32 [0.16,0.49] 50%
2014		0.77 [0.66,0.88] 14%	0.65 [0.55,0.75] 15%	0.66 [0.54,0.78] 15%	0.65 [0.50,0.80] 23%

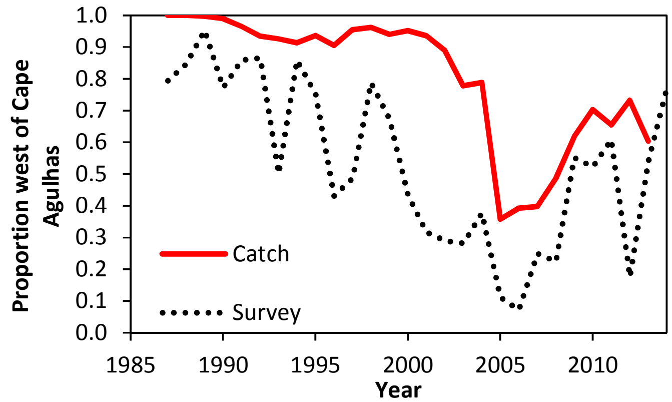

Figure 1. The observed proportion of directed sardine catch west of Cape Agulhas and the proportion of survey estimated biomass west of Cape Agulhas in November of the previous year.

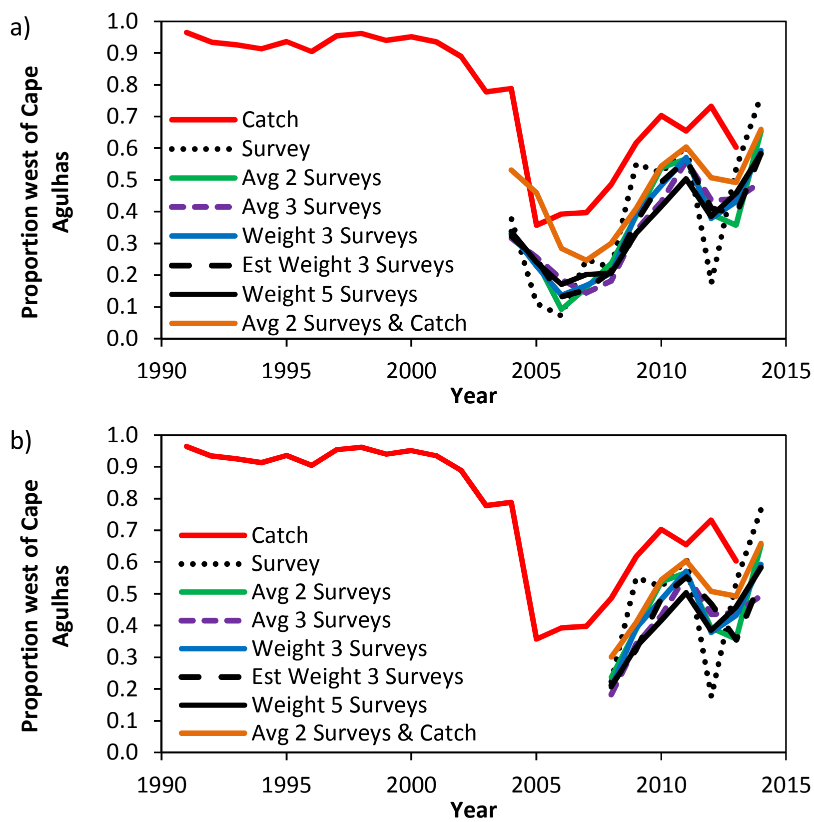

Figure 2. The observed and model predicted proportions of directed sardine **catch** west of Cape Agulhas when fitting to data from a) 2004-2013 and b) 2008-2013. Note that the model predictions are plotted *without* the additive bias, q.

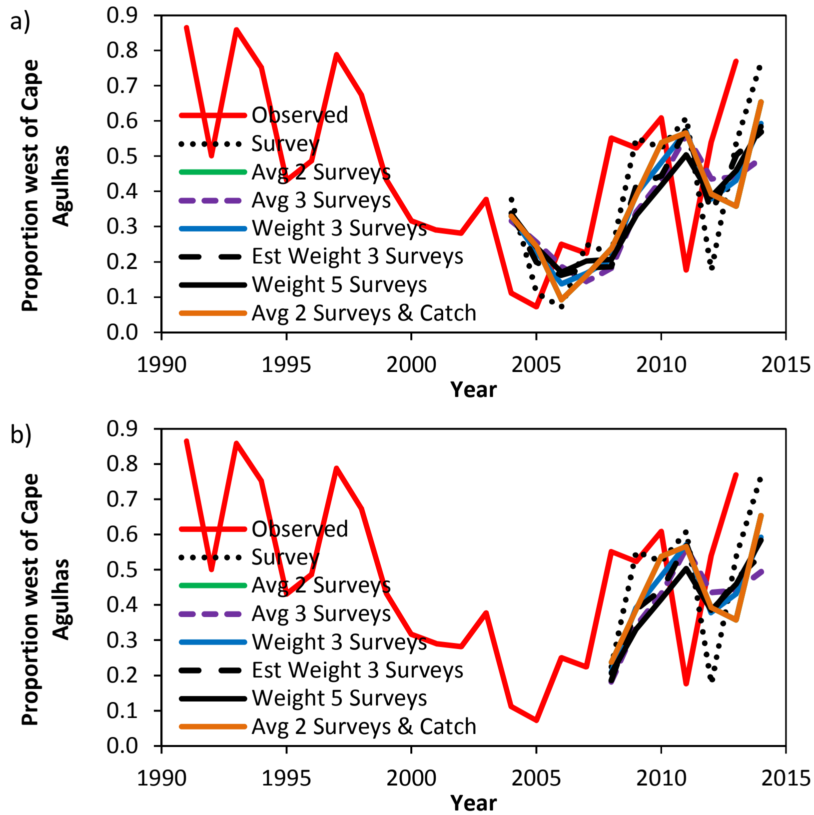

Figure 3. The observed and model predicted proportions of November **survey** estimated sardine abundance west of Cape Agulhas when fitting to data from a) 2004-2013 and b) 2008-2013. Note that the model predictions are plotted *without* the additive bias, q.

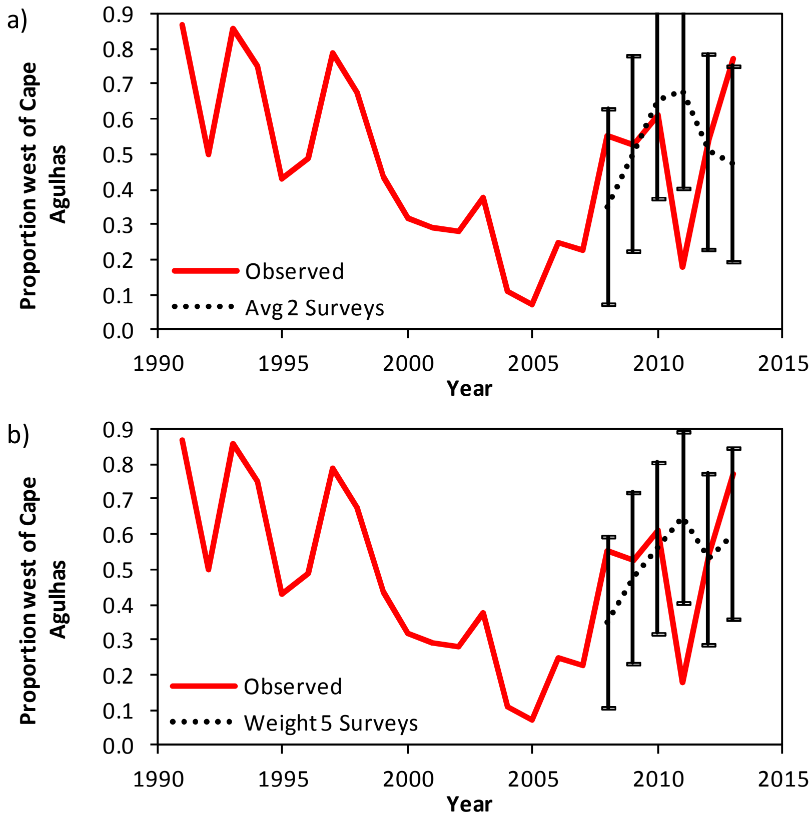

Figure 4. The observed and model predicted proportions of November survey estimated sardine abundance west of Cape Agulhas when fitting to data from 2008-2013 only for a) "Avg 2 Surveys" and b) "Weight 5 Surveys". Note that the model predictions are plotted *with* the additive bias, q, and with ±1 SE error bars.

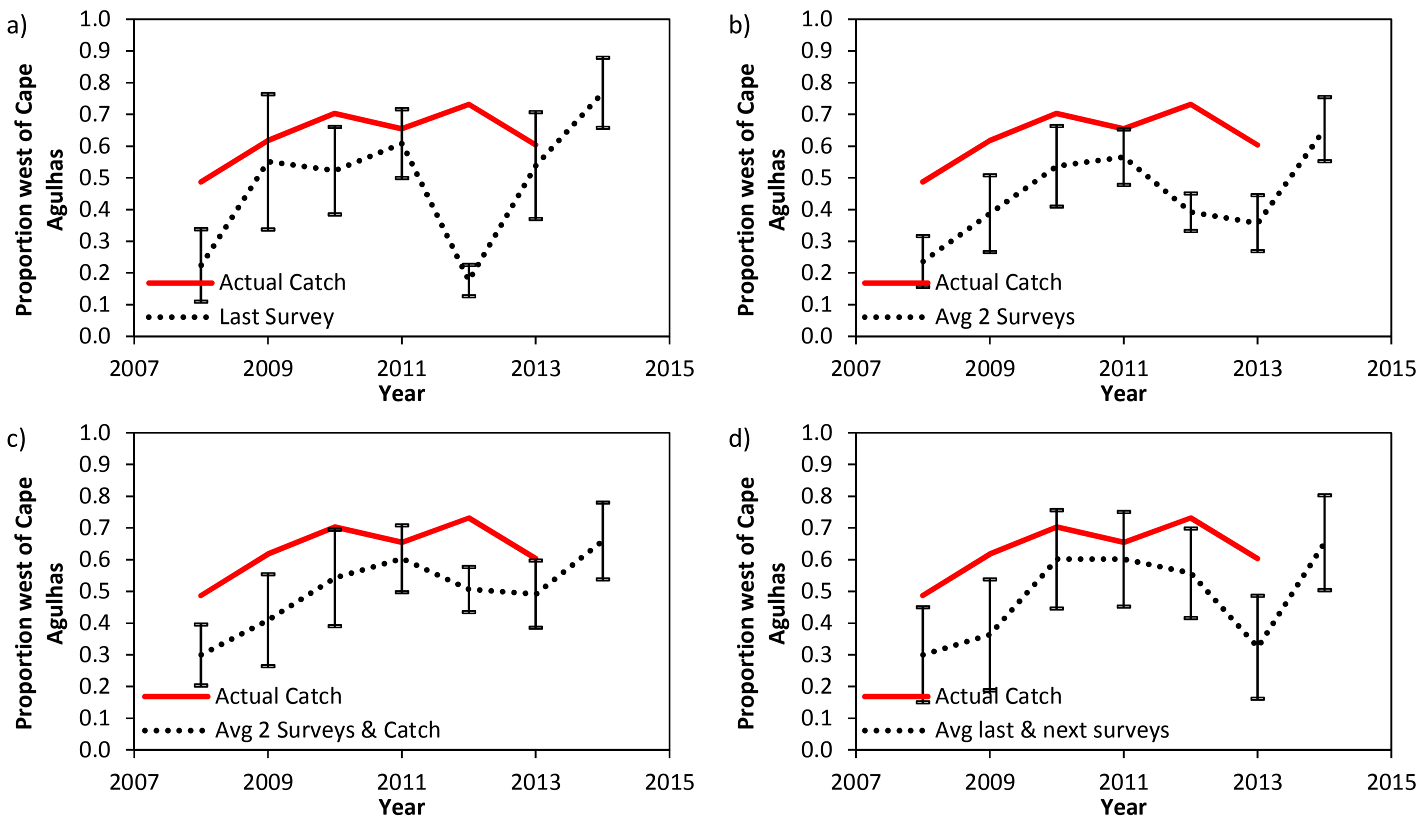

Figure 5. The actual and model recommended proportion of sardine catch west of Cape Agulhas (excluding bias in the recommended modelled proportions). The recommended sardine catch proportion in year *y* is estimated by a) the proportion of survey estimated biomass west of Cape Agulhas in November *y*-1, b) the average of the proportions of survey estimated biomass west of Cape Agulhas in Novembers *y*-1 and *y*-2, c) the average of the proportion of survey estimated biomass west of Cape Agulhas in Novembers *y*-1 and *y*-2 and the proportion of catch west of Cape Agulhas in *y*-1 and *y*-2, with greater weight given to the survey data, and d) the average of the proportions of survey biomass west of Cape Agulhas in November *y*-1 (estimated in the survey) and November *y*, where the latter proportion is predicted by model "Avg 2 surveys". The error bars indicate ±1 standard error about the model recommendations.