Statistical Catch-at-Length Assessment of *S. mentella* and *S. fasciatus* in Units 1+2

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Summary

Assessments of the two redfish species in these Units is attempted simultaneously to take account of the fact that they are distinguished only in the survey results and not in the commercial catches. Fitting the declines in the survey indices in Unit 1 for the earlier years proves a particular problem, and leads to the question of whether bounds could be placed on survey catchabilities (*q*) to avoid what seem to be some unrealistically high estimates of *q* for *S. fasciatus*. Allowing for occasional large recruitments in these populations shows promise for improving the fits to those survey indices. However this needs further investigation to determine whether associated poor fits to the survey catch-at-length data can be avoided, and whether estimation stability can be improved.

Introduction

This document presents results from an application of a Statistical Catch-at-Length (SCAL) assessment approach to the *S. mentella* and *S. fasciatus* resources in Units 1+2. Because (unlike the survey data) the commercial catch data available for this region is species-aggregated, the approach assesses both species simultaneously so as to be able to fit to these species-combined data.

The results presented in this document fall into two sections. First there are those for some initial runs which were discussed at a teleconference in early March 2014 (though slightly modified for reasons given below). Following that teleconference, ideas for further runs were offered and subsequently developed, and those follow in a second section.

Data and Methods

The data used are listed in Appendix A.

The methodology, detailed in Appendix B, is broadly as described in Rademeyer and Butterworth (2011), with some key features and changes described below:

1) An age-structured model is used rather than an age-aggregated approach (as in McAllister and Duplisea, 2012) for a more realistic representation of the dynamics.
2) The new Campana ageing data are used: for each species, a von Bertalanffy growth curve through the origin has been fitted to these data and the resulting parameters used in the assessment.
3) Instead of assuming a knife-edged maturity-at-age 9, a knife-edged maturity-at-length 22 cm is assumed which is then converted to maturity-at-age using the estimated length-at age distributions.
4) Although the survey biomass index is taken as the mature biomass only (≥22cm), the model is now fitted to the whole range of survey catch-at-length data available.

5) Because the commercial catches and catch-at-length data are not disaggregated by species, the assessment models both species simultaneously.
6) No assumption about the species split of the catches is made on input; rather flexibility is allowed in the model by estimating the annual *S. fasciatus* proportion in the catches directly, by means of the following penalty added to the negative log-likelihood:

$$-\ell nL^{FPpen} = \sum_{u}\sum_{y=1960}^{2009}\left[\frac{\left(p_y^u - \mu^u\right)^2}{2\left(\sigma^u\right)^2}\right] \qquad (1)$$

where

p_y^u is the estimated proportion of *S. fasciatus* in the catch in year *y* and Unit *u*,

μ^u and σ^u are the mean and standard deviation respectively of the distribution of *S. fasciatus* proportions in Unit *u* based on the survey species split information (McAllister and Duplisea, 2012). For Unit 1, $\mu^u = 0.40$ and $\sigma^u = 0.16$, and for Unit 2, $\mu^u = 0.53$ and $\sigma^u = 0.10$.
7) Scenarios with occasional high recruitments are implemented by allowing a large variability about the stock-recruitment relationship (σ_R = 1.5), essentially permitting the recruitments to be estimated freely.
8) For the scenarios with a change in carrying capacity, the changes are modelled as a random walk (separately for each species):

$$K_y = K_{y-1}e^{\varepsilon_y} \qquad (2)$$

with the following penalty added to the negative log-likelihood:

$$-\ell nL^{Kpen} = \sum_{y=1961}^{2009}\left[\varepsilon_y^2 / 2\sigma_K^2\right] \qquad (3)$$

with ε_y estimated in the model fitting procedure and $\sigma_K = 0.3$.
9) A penalty on the survey catchability coefficients is used for all scenarios in the spirit of a prior to avoid the results going into implausible regions of parameter space (particularly *S. fasciatus'* survey catchability *q* going unrealistically high). The following penalty is added to the negative log-likelihood to effect this:

$$-\ell nL^{qpen} = \sum_{i=1}^{n_{survey}}\left[\frac{2\left(q^i - l_b\right)}{\left(u_b - l_b\right)} - 1\right]^p \qquad (4)$$

with the upper and lower bounds (l_b and u_b) chosen as: $l_b = 0.2$, $u_b = 2.0$ and $p = 16$
10) The catch-at- length data are downweighted by a factor of 0.01 instead of 0.1 in Rademeyer and Butterworth (2011). This is to ensure that catch-at-length information does not unduly influence the model's attempt to fit the survey index data.
11) In the cases where log-normally distributed fluctuations about the stock-recruitment relationship are admitted, and with a high value for the extent of variability σ_R = 1.5 to allow for the possibility of occasional very large recruitments, the starting abundance and age-structure corresponds to median rather than to mean recruitment (and carrying capacity *K* similarly) so that this reflects the typical situation *absent* those large year classes.

Results

First results for four runs are presented:

1) "σ_R=0.4": does not allow for occasional high recruitment or changes in carrying capacity.

2) "σ_R=1.5": allows for occasional high recruitment.
3) "σ_R=0.4, with changes in *K*": makes allowance for changes in the carrying capacities for each species.
4) "σ_R=0.4, with changes in *K*, more weight 1990-1995 surveys": as 3) above, but with more weight (*W*=10) added to the 1990-1995 survey data points. This scenario was selected because no other run fits the early survey index declines.

Table 1 compares the results for these four scenarios. Note that compared to material circulated for the March teleconference, results for 2) differ because of the modification indicated in note 11) above – consequently this is termed scenario 2a in this paper. Furthermore results for 4) also differ slightly because of an earlier error in the value accorded to W_{CAL} for this run.

The fits to the survey biomass indices for *S. mentella* and *S. fasciatus* are plotted in Figure 1 for each of the four scenarios, while Figure 2 compares the spawning biomass and recruitment trajectories.

Figures 3 to 5 give more detailed results for scenario 2a (σ_R=1.5). Figure 3 plots the catch trajectories by species and Unit as well as the estimated *S. fasciatus* proportion in the catch for this scenario. The estimated survey and commercial selectivities are shown in Figure 4. The commercial selectivities are taken to be the same for Unit 1 and Unit 2. Finally Figure 5 plots the fits to the survey biomass and catch-at-length data.

At the March 2014 teleconference, a further series of scenarios were suggested and some more have been added by the authors. The corresponding runs have been based on the σ_R=1.5 run (scenario 2a – as this was considered at the teleconference to hold the most promise) for all except one scenario (scenario 5). Scenario 5 is based on run1 (σ_R=0.4) because that yields values for *q* which are closer to the Bundy estimate than are the *q* values for run 2a (σ_R=1.5).

5) Fixed *q*=0.43 (as advised to correspond to the estimate by Alida Bundy).
6) Lessen the prior constraints on *q* (bounds changed to 0.1 to 5).
7) Flat survey selectivity from length 30cm onwards.
8) Alternative priors for the species split of the catches, keeping the standard deviation as in run 2 a. for Unit 1, $\mu^1 = 0.60$ and for Unit 2, $\mu^2 = 0.73$ and b. for Unit 1, $\mu^1 = 0.20$ and for Unit 2, $\mu^2 = 0.33$.
9) Logistic survey selectivities.
10) Allow for large recruitment variability, forcing a fit to the early survey declines.

Tables 2 and 3 compare results for the scenarios described above. Results for scenario 5 (fixed *q*=0.43) are shown in Table 2 together with the corresponding scenario 1 results, while results for the other scenarios are given in Table 3.

The fits to the survey biomass indices for *S. mentella* and *S. fasciatus* are plotted in Figures 6 and 7 for the scenarios described above.

The fits to the survey CAL data for scenarios 2a (σ_R=1.5, W_{CAL}=0.01) and 2b (σ_R=1.5, W_{CAL}=0.1) are compared in Figure 8.

Figure 9 plots the commercial and survey selectivities-at-length for scenario 7, for which the survey selectivities are forced flat from length 30cm onward.

Estimated species-disaggregated catch trajectories and *S. fasciatus* proportions in the catches are compared in Figure 10 for scenarios 2a, 8a and 8b, which assume different priors for the species split of the catches.

Discussion

First the results reported for the teleconference and the impact of some subsequent adjustments to those are discussed.

1) Previously it was reported that occasional high recruitment or changes in *K* could partly explain the earlier *S. fasciatus* survey results, but not the *S. mentella* ones. Hence run 4) is introduced, "forcing" the model to fit both those Unit 1 early declines. With the modification of methodology note 11) to commence with , the occasional high recruitment option of run 2a) ***can*** explain the earlier *S. mentella* decline through a large increase in the estimated size of the 1981 year class, but there are some associated problems as discussed further below.
2) All of runs 2a) to 4) set high values for survey catchability for *S. fasciatus* in Unit 2 in particular in an attempt to reduce estimates of recent biomass so as to be able to better reflect the decline in the *S. fasciatus* survey index in Unit 1 over 1990-1995.
3) Run 2a), with high σ_R=1.5 to allow for occasional high recruitment pulses (as indeed are then estimated – see Fig. 2), leads to a higher estimate of *K* for *S. mentella* which is less depleted relative to *K*, though *S. fasciatus* is more depleted relative to *K*. (this again differs from the results reported for the teleconference as a consequence of method modification 11).
4) Forcing the varying *K* scenario to fit the early survey index declines in Unit 1 in run 4) leads to higher estimated initial *K* and some higher survey catchability *q* values for both species, The current biomass estimated for *S. mentella* is appreciably less.

Specifically in relation to the Figures shown for scenario 2 only (though these points also apply to the other scenarios):

- There seems little information in the process to update the “prior” on the *S. fasciatus* proportion of the catch appreciably (Figure 3).
- The low survey selectivities in the 20-30cm range (Figure 4) are surprising. The follow from the observed length frequency distributions. What mechanism is responsible for the absence of these lengths in the survey data?

The following are features of interest in the results for the sensitivities suggested at the teleconference and related further runs.

5) Scenario 2a) seems very promising in showing an ability to fit the initial decline in the survey index for *S. mentella* for Unit 1 by estimating a very large 1981 year-class (Figures 1 and 2). However, that is at the cost of a severe misfit to the corresponding CAL data (Figure 5), with an absence in the model of the larger *S. mentella* observed in these surveys. If the weight on these CAL data is increased (scenario 2b), they are fitted much better (Figure 8), but then the initial decline in the index is no longer reflected (Figure 6). Thus basically there is a conflict between these two data sources given the current model, which further work should attempt to resolve.
6) Setting *q*=0.43 (scenario 5) makes effectively no difference to the results from the comparative scenario 1 with σ_R=0.4 (Table 2 and compare Figures 6 and 1).

7) Scenario 6 which widens the constraints on the range for *q* leads to a slightly better fit to the early decline in the abundance index for *S. fasciatus* in Unit 1 (Figure 6), but the estimates of the corresponding survey *q*'s become extremely high (Table 3).
8) Flattening survey selectivity above a length of 30 cm (scenario 7) makes little difference to estimates of importance for management (Table 3).
9) Changing the prior for the species split of the catch to reflect a bigger proportion of *S. fasciatus* (scenario 8a) improves the fit overall (slightly) and particularly that to the early Unit 1 *S. fasciatus* survey index decline (Table 3 and Figure 7). A change in the prior in the other direction leads to a deterioration in the fit to this early decline for both species.
10) A logistic form for the survey selectivities (scenario 9) leads to an appreciable deterioration in the fits to the *S. mentella* survey index of abundance (Table 3 and Figure 7).
11) Forcing a fit to the early survey indices in Unit 1 for both species (scenario 10, Figure 7) leads to a deterioration in the fit to the commercial CAL data in particular, but does suggest that the *S. fasciatus* population is less depleted relative to *K* (Table 3).

Overall, though the possibility of allowing for occasional high recruitments shows promise, in particular as a means of accounting for the initial declines in the survey indices in Unit 1 for both species, we must stress that convergence of the model fit is difficult to achieve for this approach. More work is needed to improve the estimation stability of this approach before the results which it provides could be regarded as reliable.

Further work

Issues meriting further discussion include:

- Restrictions (particularly upper bounds) to be placed on the survey catchabilities *q*.
- The importance of an assessment reflecting the 1990-1995 declines in the survey index for both species in Unit 1.
- Possible further spatial sub-structuring of the assessment to be able to accommodate (*inter alia*) further surveys with only partial coverage of a Unit.
- Alternative approaches to modelling occasional high recruitments (mixture distributions perhaps?), and whether there is further information that might be included to assist stablisethe assessment when such possibilities are admitted.

References

McAllister M and Duplisea DE. 2012. Production model fitting and projection for Acadian redfish (*Sebastes fasciatus*) in Units 1 and 2. DFO Can. Sci. Advis. Sec. Res. Doc. 2012/103. iii + 34p.

Rademeyer RA and Butterworth DS. 2011. Initial applications of statistical catch-at-age assessment methodology to Atlantic redfish. Document submitted to Canadian ZAP meeting related to Precautionary Approach reference points for redfish populations, Mont-Joli, October 2011: 34pp.

Table 1: Results of fits of **scenarios 1 to 4** for redfish in Units 1 + 2. Values fixed on input rather than estimated are shown in **bold**. Mass units are '000t. In cases where the value of the pre-exploitation spawning biomass *K* changes within the assessment period, the two columns for K^{sp} reports the carrying capacity in the first and last year of the assessment period respectively. The value of W_{CAL} is 0.01 for all these runs.

	1) σ_R=0.4				2a*) new σ_R=1.5				3) σ_R=0.4, with changes in *K*				4) σ_R=0.4, with *K* changes, more weight 1990-1995 surveys			
-lnL: overall	-157.9				-53.3				-180.8				-247.7			
-lnL: survey	13.0				-18.6				-13.0				-108.6			
-lnL: survCAL	-38.8				-35.0				-39.4				-33.7			
-lnL: comCAL	-44.3				-47.7				-43.1				-32.2			
-lnL: catchpen	0.00				0.00				0.00				0.00			
-lnL: FascProppen	0.18				0.22				0.25				5.78			
-lnL: SRpen	-88.53				47.56				-89.58				-88.88			
-lnL: qpen	0.56				0.26				0.13				1.45			
-lnL: Kpen									3.86				8.42			
	S. mentella		*S. fasciatus*		*S. mentella*		*S. fasciatus*		*S. mentella*		*S. fasciatus*		*S. mentella*		*S. fasciatus*	
h	**0.67**		**0.67**		**0.67**		**0.67**		**0.67**		**0.67**		**0.67**		**0.67**	
M	**0.100**		**0.125**		**0.100**		**0.125**		**0.100**		**0.125**		**0.100**		**0.125**	
θ	**1.00**		**1.00**		**1.00**		**1.00**		**1.00**		**1.00**		**1.00**		**1.00**	
ζ	**0.00**		**0.00**		**0.00**		**0.00**		**0.00**		**0.00**		**0.00**		**0.00**	
K^{sp}	1299		724		1741		704		1090	72	1156	281	2039	202	2228	539
B^{sp}_{2009}	946		519		1599		132		101		124		60		174	
B^{sp}_{2009}/K^{sp}	0.73		0.72		0.92		0.19		0.09	1.40	0.11	0.44	0.03	0.30	0.08	0.32
$MSYL^{sp}$	0.3		0.4		0.30		0.30		0.31		0.30		0.32		0.31	
B^{sp}_{MSY}	452.7		280.1		527.2		210.7		22.2		83.2		65.7		168.2	
MSY	56.2		37.7		203.0		98.0		3.0		14.2		8.3		27.4	
Survey	*q*'s	σ_{Add}	*q*'s	σ_{Add}	*q*'s	σ_{Add}	*q*'s	σ_{Add}	*q*'s	σ_{Add}	*q*'s	σ_{Add}	*q*'s	σ_{Add}	*q*'s	σ_{Add}
Unit 1	0.25	0.87	0.29	0.99	1.49	0.27	1.06	0.56	0.62	0.45	0.89	0.54	1.49	0.16	1.93	0.30
Unit 2	0.58	0.31	0.68	0.32	0.30	0.13	1.88	0.27	1.69	0.08	1.89	0.30	1.98	0.00	1.96	0.27
σ_R_out	0.07		0.06		0.69		0.49		0.03		0.02		0.05		0.06	

* This is not identical to the run considered during the March teleconference, as the starting biomass corresponds to median rather than mean recruitment – see note 11) under Data and Methods.

Table 2: Results of fits of **scenarios 1 and 5** (all *q*'s fixed at 0.43) for redfish in Units 1 + 2. Values fixed on input rather than estimated are shown in **bold**. Mass units are '000t.

	1) σ_R=0.4				5) σ_R=0.4, q=0.43			
-lnL: overall	-157.9				-150.2			
-lnL: survey	13.0				16.8			
-lnL: survCAL	-38.8				-36.2			
-lnL: comCAL	-44.3				-42.6			
-lnL: catchpen	0.00				0.00			
-lnL: FascProppen	0.18				0.59			
-lnL: SRpen	-88.53				-88.88			
-lnL: qpen	0.56				0.13			
-lnL: Kpen								
	S. mentella		*S. fasciatus*		*S. mentella*		*S. fasciatus*	
h	**0.67**		**0.67**		**0.67**		**0.67**	
M	**0.100**		**0.125**		**0.100**		**0.125**	
θ	**1.00**		**1.00**		**1.00**		**1.00**	
ζ	**0.00**		**0.00**		**0.00**		**0.00**	
K^{sp}	1299		724		991		743	
B^{sp}_{2009}	946		519		688		536	
B^{sp}_{2009}/K^{sp}	0.73		0.72		0.69		0.72	
$MSYL^{sp}$	0.3		0.4		0.32		0.31	
B^{sp}_{MSY}	452.7		280.1		317.1		230.7	
MSY	56.2		37.7		40.2		37.1	
Survey	*q*'s	σ_{Add}	*q*'s	σ_{Add}	*q*'s	σ_{Add}	*q*'s	σ_{Add}
Unit 1	0.25	0.87	0.29	0.99	0.43	0.99	0.43	1.00
Unit 2	0.58	0.31	0.68	0.32	0.43	0.33	0.43	0.31
σ_R_out	0.07		0.06		0.03		0.07	

Table 3: Results of fits of **scenarios 2a and 2b, and 6 to 10** for redfish in Units 1 + 2. Values fixed on input rather than estimated are shown in **bold**. Mass Units are '000t. The value of W_{CAL} is 0.01 unless otherwise indicated.

	2a) σ_R=1.5, W_{CAL}=0.01	2b) σ_R=1.5, W_{CAL}=0.1	6) σ_R=1.5, q prior 0.1-5	7) σ_R=1.5, flat survey sel from 30cm	8a) σ_R=1.5, spp split median +0.2	8b) σ_R=1.5, spp split median -0.2	9) σ_R=1.5, *logistic survey sel*	10) σ_R=1.5, more weight on last 5 years' survey biomass data
-lnL: overall	-53.3	-867.2	-56.1	-51.5	-54.7	-50.9	-39.7	-156.9
-lnL: survey	-18.6	0.1	-19.8	-15.3	-19.8	-15.0	-6.4	-151.5
-lnL: survCAL	-35.0	-434.6	-35.9	-36.0	-35.1	-35.8	-33.0	-31.0
-lnL: comCAL	-47.7	-490.7	-47.3	-47.3	-47.7	-47.3	-47.4	-39.5
-lnL: catchpen	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
-lnL: FascProppen	0.22	0.13	0.15	0.21	0.11	0.54	0.17	8.16
-lnL: SRpen	47.56	56.12	46.38	46.63	47.54	46.41	46.14	55.65
-lnL: qpen	0.26	1.65	0.42	0.28	0.27	0.17	0.77	1.36
-lnL: Kpen								

	2a)		2b)		6)		7)		8a)		8b)		9)		10)	
	S. mentella	*S. fasciatus*	*S. mentella*	*S. fasciatus*	*S. mentella*	*S. fasciatus*	*S. mentella*	*S. fasciatus*	*S. mentella*	*S. fasciatus*	*S. mentella*	*S. fasciatus*	*S. mentella*	*S. fasciatus*	*S. mentella*	*S. fasciatus*
h	**0.67**	**0.67**	**0.67**	**0.67**	**0.67**	**0.67**	**0.67**	**0.67**	**0.67**	**0.67**	**0.67**	**0.67**	**0.67**	**0.67**	**0.67**	**0.67**
M	**0.100**	**0.125**	**0.100**	**0.125**	**0.100**	**0.125**	**0.100**	**0.125**	**0.100**	**0.125**	**0.100**	**0.125**	**0.100**	**0.125**	**0.100**	**0.125**
θ	**1.00**	**1.00**	**1.00**	**1.00**	**1.00**	**1.00**	**1.00**	**1.00**	**1.00**	**1.00**	**1.00**	**1.00**	**1.00**	**1.00**	**1.00**	**1.00**
ζ	**0.00**	**0.00**	**0.00**	**0.00**	**0.00**	**0.00**	**0.00**	**0.00**	**0.00**	**0.00**	**0.00**	**0.00**	**0.00**	**0.00**	**0.00**	**0.00**
K^{sp}	1741	704	1165	658	2143	635	1994	728	1226	929	2310	500	1595	668	1413	474
B^{sp}_{2009}	1599	132	986	110	2051	63	1864	127	1159	141	2032	121	1129	133	1570	209
B^{sp}_{2009}/K^{sp}	0.92	0.19	0.85	0.17	0.96	0.10	0.93	0.17	0.95	0.15	0.88	0.24	0.71	0.20	1.11	0.44
$MSYL^{sp}$	0.30	0.30	0.30	0.30	0.30	0.30	0.30	0.30	0.30	0.30	0.30	0.30	0.30	0.30	0.32	0.31
B^{sp}_{MSY}	527.2	210.7	351.1	196.4	647.9	190.0	603.1	218.0	372.1	278.3	698.5	149.6	483.2	199.9	453.6	148.1
MSY	203.0	98.0	136.1	91.8	248.3	87.6	231.9	101.0	143.7	130.3	268.0	69.1	187.4	94.0	172.9	71.5
σ_R_out	0.69	0.49	0.94	0.79	0.64	0.44	0.65	0.46	0.68	0.50	0.66	0.42	0.61	0.47	0.83	0.88

	2a)				2b)				6)				7)				8a)				8b)				9)				10)			
Survey	q's	σ_{Add}	q's	σ_{Add}	q's	σ_{Add}	q's	σ_{Add}	q's	σ_{Add}	q's	σ_{Add}	q's	σ_{Add}	q's	σ_{Add}	q's	σ_{Add}	q's	σ_{Add}	q's	σ_{Add}	q's	σ_{Add}	q's	σ_{Add}	q's	σ_{Add}	q's	σ_{Add}	q's	σ_{Add}
Unit 1	1.49	0.27	1.06	0.56	0.18	0.79	0.55	0.63	0.65	0.31	2.62	0.48	0.74	0.31	0.59	0.61	1.48	0.27	1.07	0.53	0.72	0.31	1.03	0.62	0.22	0.68	1.61	0.53	1.84	0.00	1.92	0.27
Unit 2	0.30	0.13	1.88	0.27	0.36	0.13	1.88	0.31	0.27	0.13	4.67	0.25	0.29	0.13	1.88	0.27	0.29	0.13	1.88	0.26	0.33	0.13	1.88	0.27	0.51	0.11	1.87	0.26	0.23	0.19	1.96	0.19

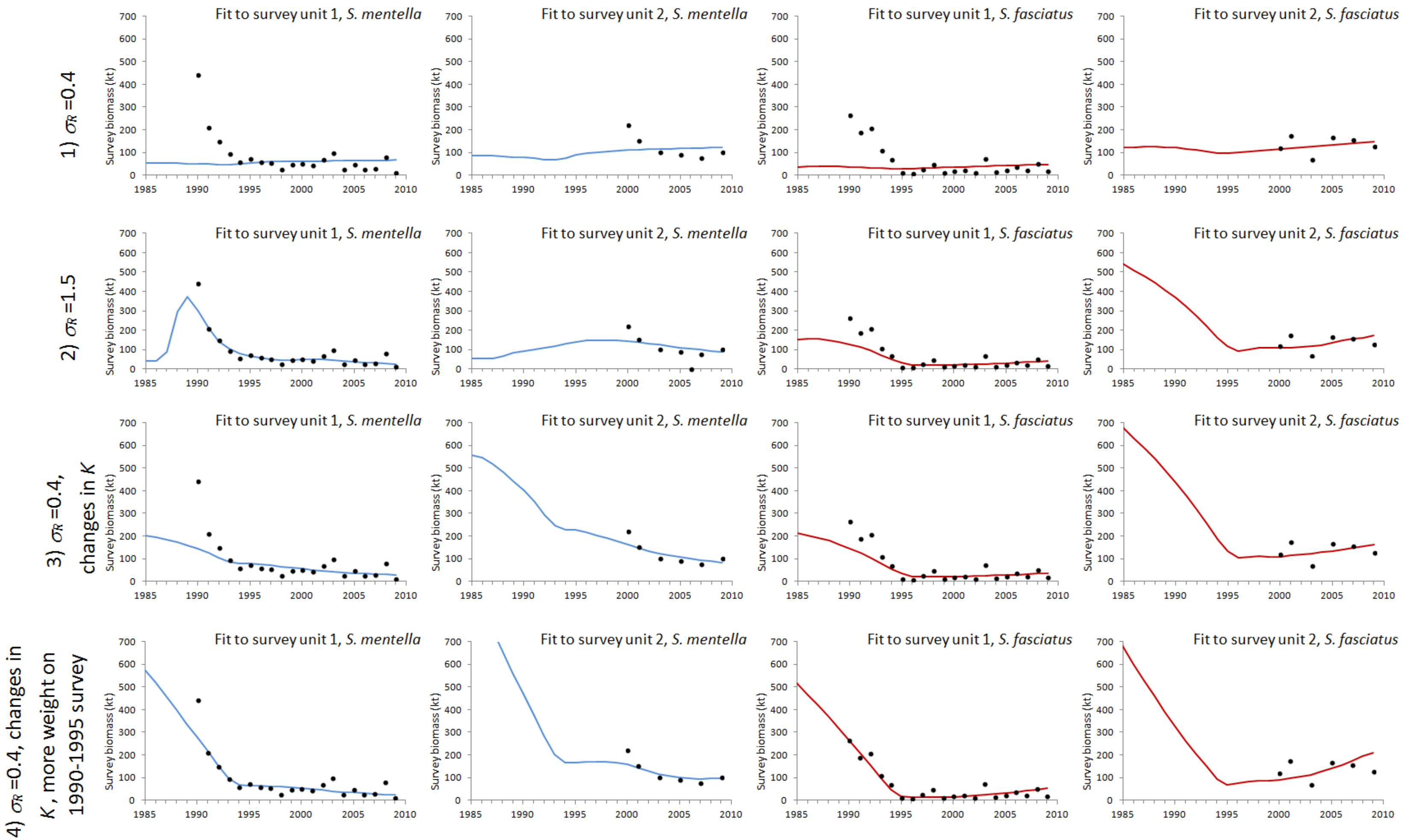

Figure 1: Fits to the survey biomass indices for **scenarios 1 to 4**.

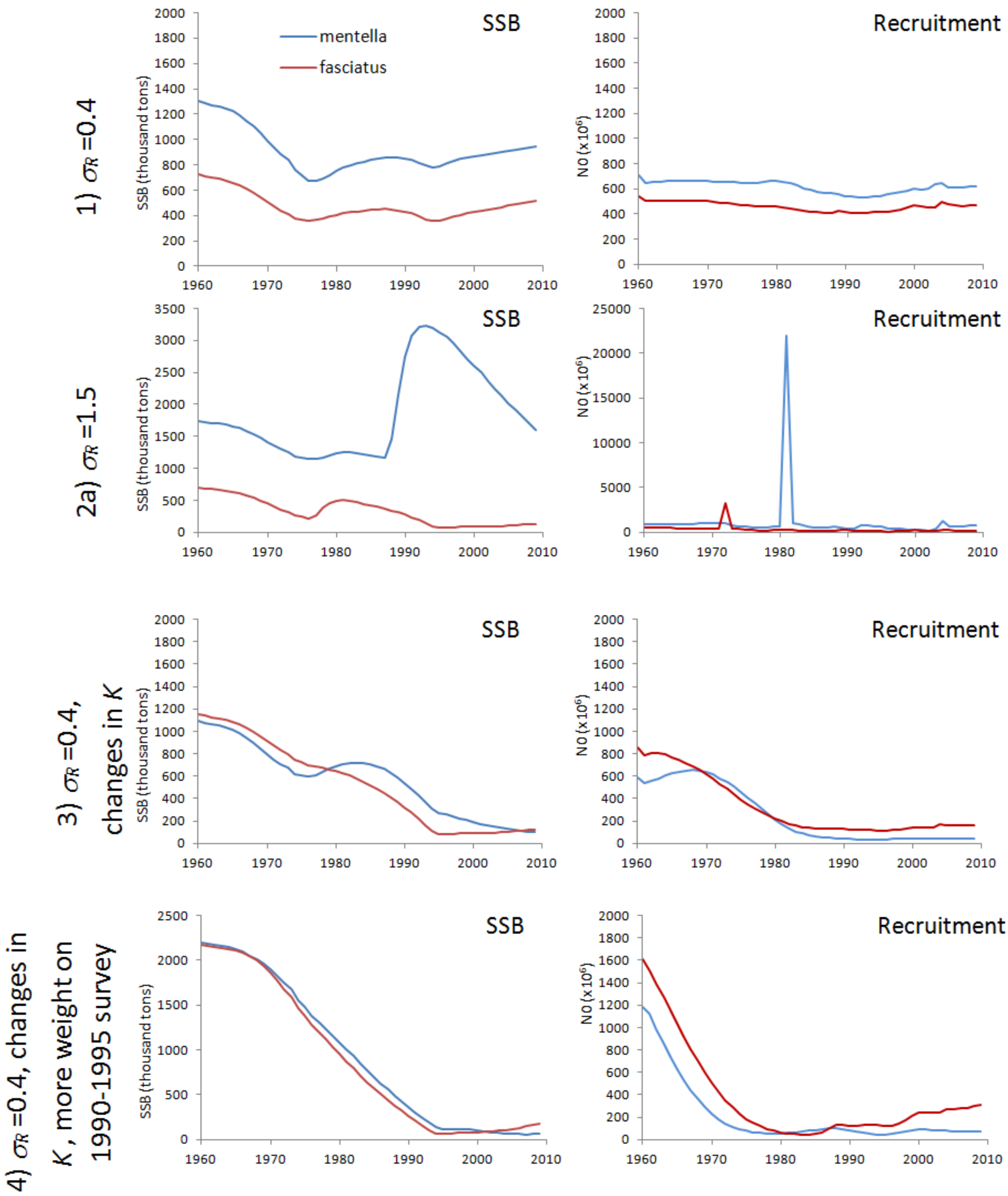

Figure 2: Spawning biomass and recruitment trajectories for *S. mentella* (blue lines) and *S. fasciatus* (red lines) for **scenarios 1 to 4**.

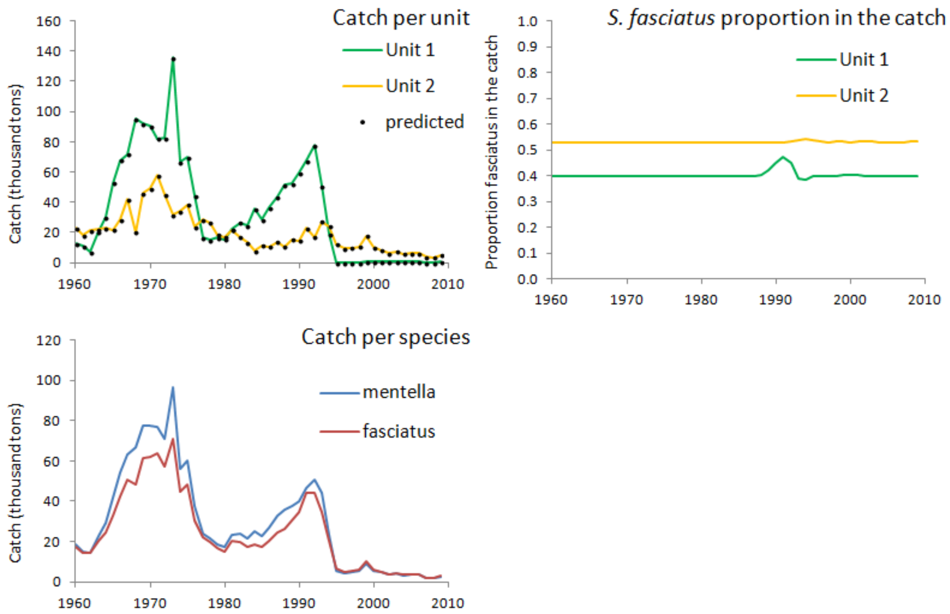

Figure 3: Catch trajectories by Unit and species, and estimated *S. fasciatus* proportion in the catch for **scenario 2a (σ_R=1.5, W_{CAL}=0.01)**.

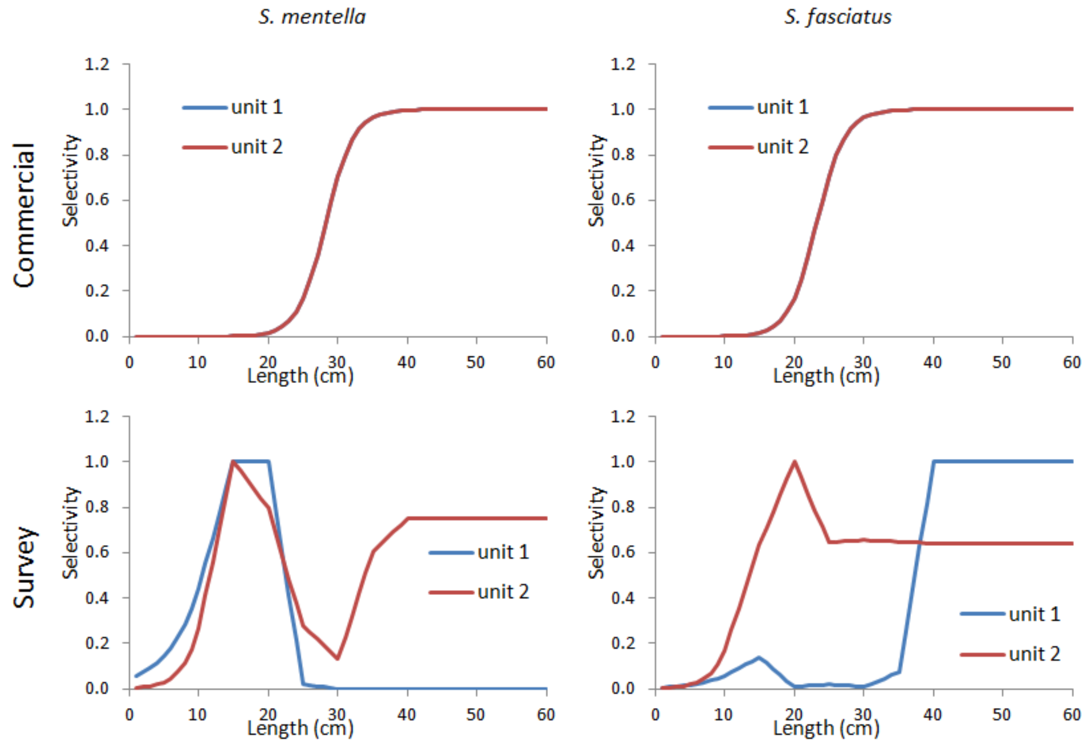

Figure 4: Commercial and survey selectivities-at-length for **scenario 2a (σ_R=1.5, W_{CAL}=0.01)**.

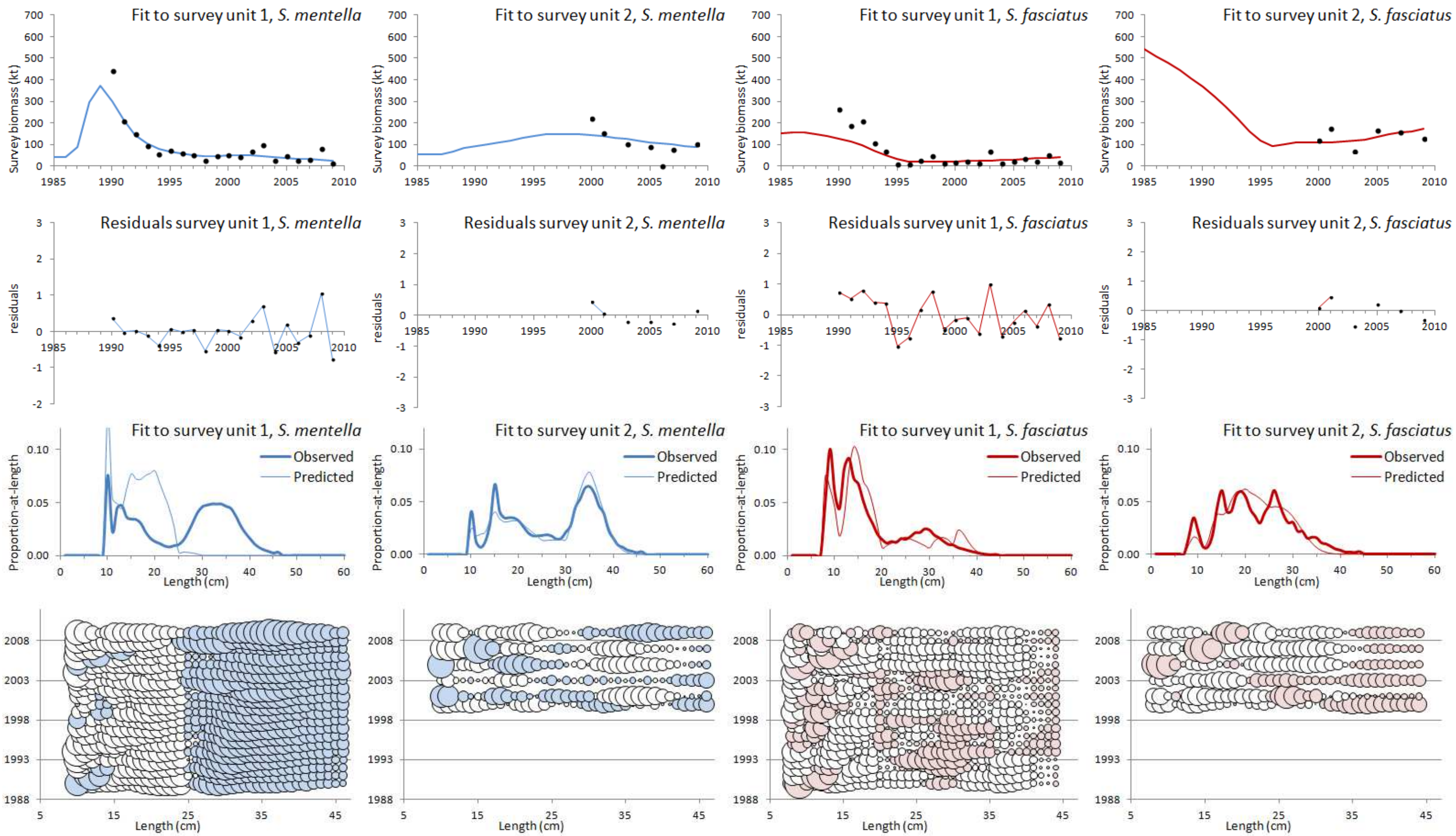

Figure 5: For **scenario 2a (σ_R=1.5, W_{CAL}=0.01)**, fits to the survey biomass indices (first row), corresponding residuals (second row), fits to CAL data (as averaged over all the years for which data are available) (third row) and bubble plots of the standardised residuals for the fit to the CAL data (last row). The area of the bubble is proportional to the magnitude of the corresponding standardised residuals. For positive residuals the bubbles are blue/pink, whereas for negative residuals the bubbles are white.

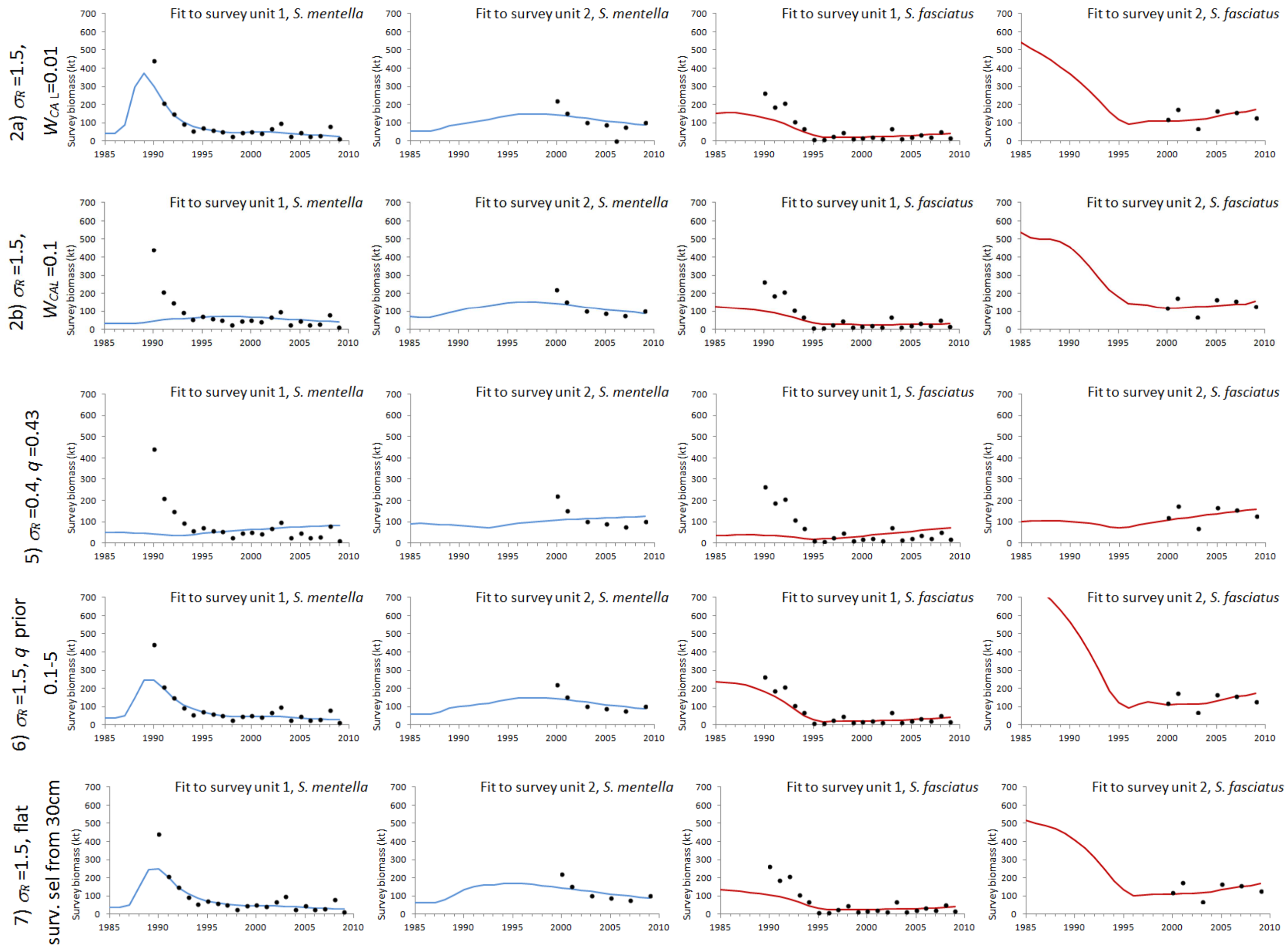

Figure 6: Fits to the survey biomass indices for **scenarios 2a and 2b and 5 to 7.**

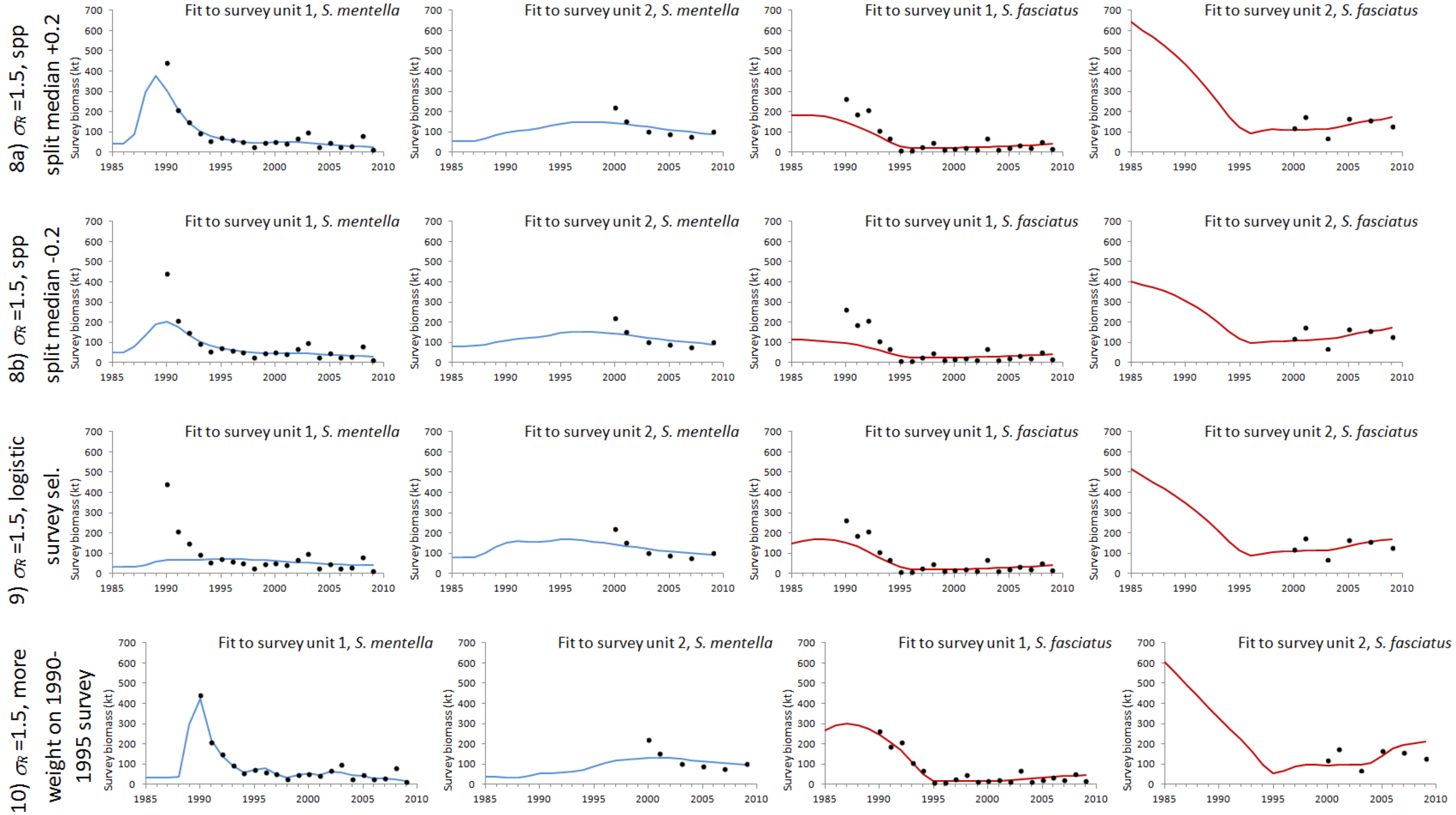

Figure 7: Fits to the survey biomass indices for **scenarios 8a to 10.**

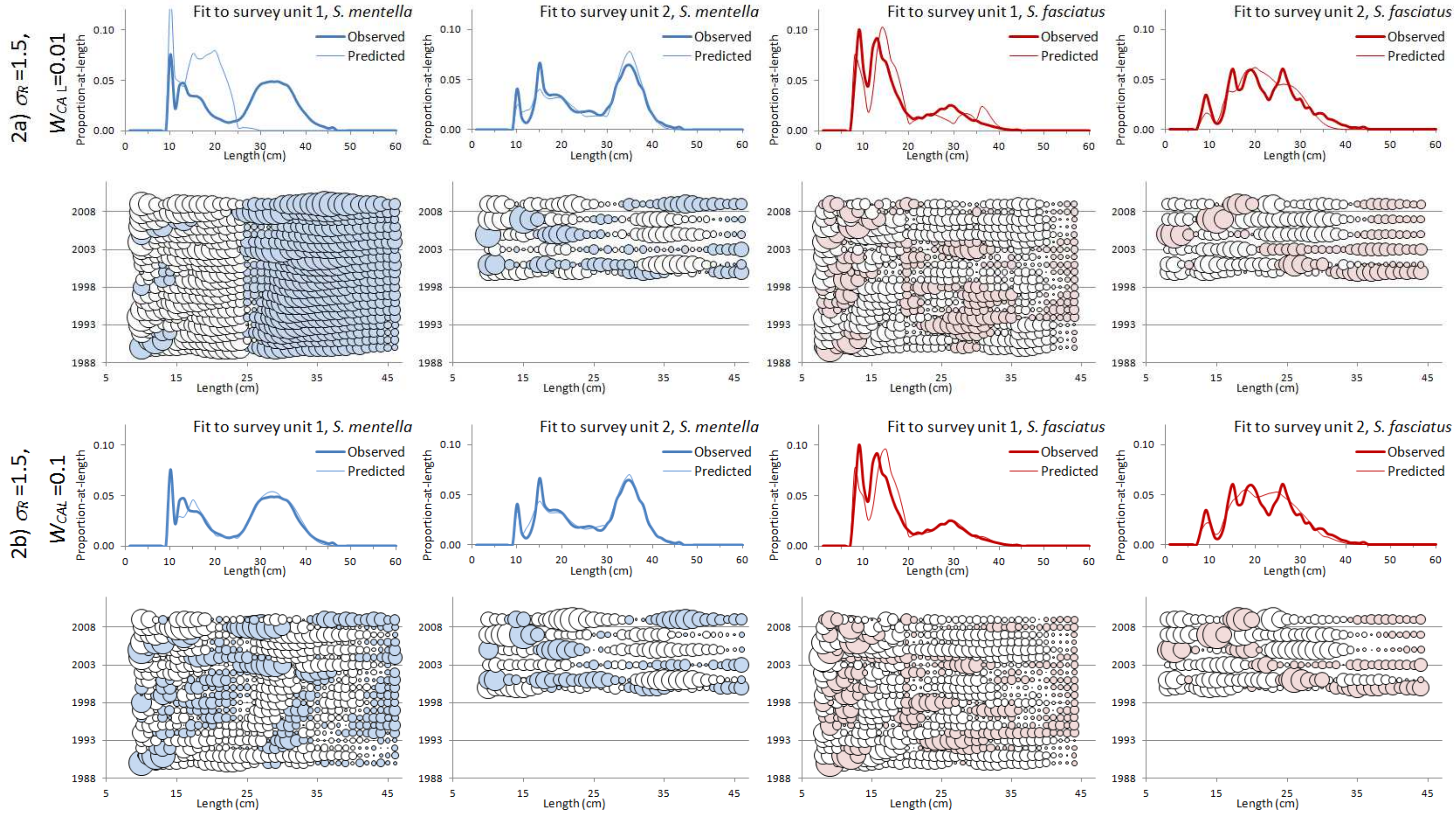

Figure 8: For **scenarios 2a (σ_R=1.5, W_{CAL}=0.01) and 2b (σ_R=1.5, W_{CAL}=0.1)**, fits to CAL data (as averaged over all the years for which data are available) (third row) and bubble plots of the standardised residuals for the fit to the CAL data (last row). The area of the bubble is proportional to the magnitude of the corresponding standardised residuals. For positive residuals the bubbles are blue/pink, whereas for negative residuals the bubbles are white.

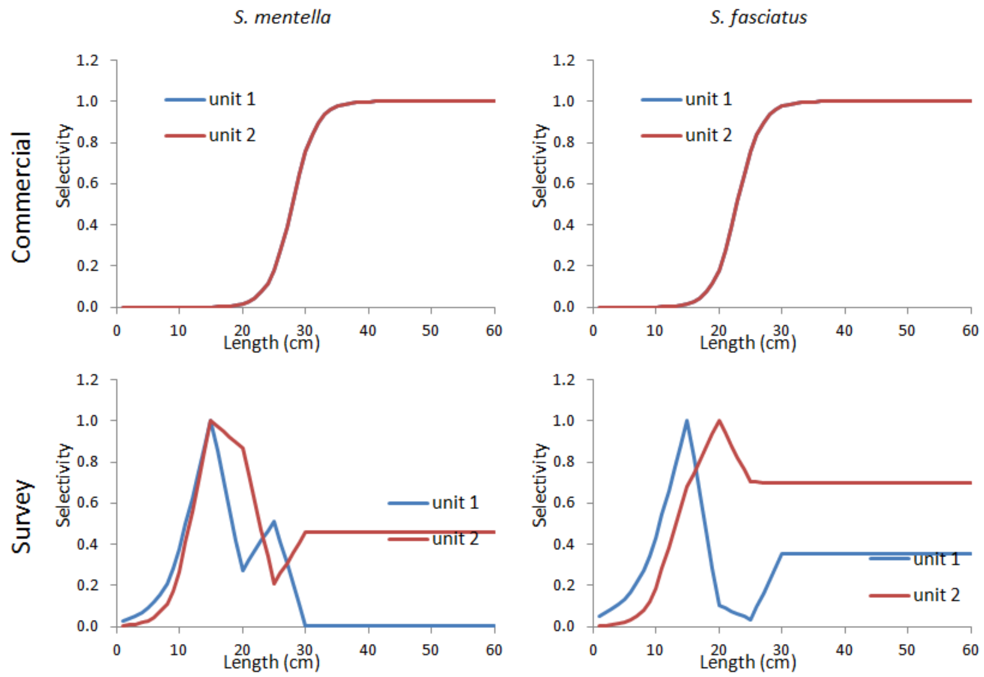

Figure 9: Commercial and survey selectivities-at-length for **scenario 7 (σ_R=1.5, flat survey selectivity from 30cm).**

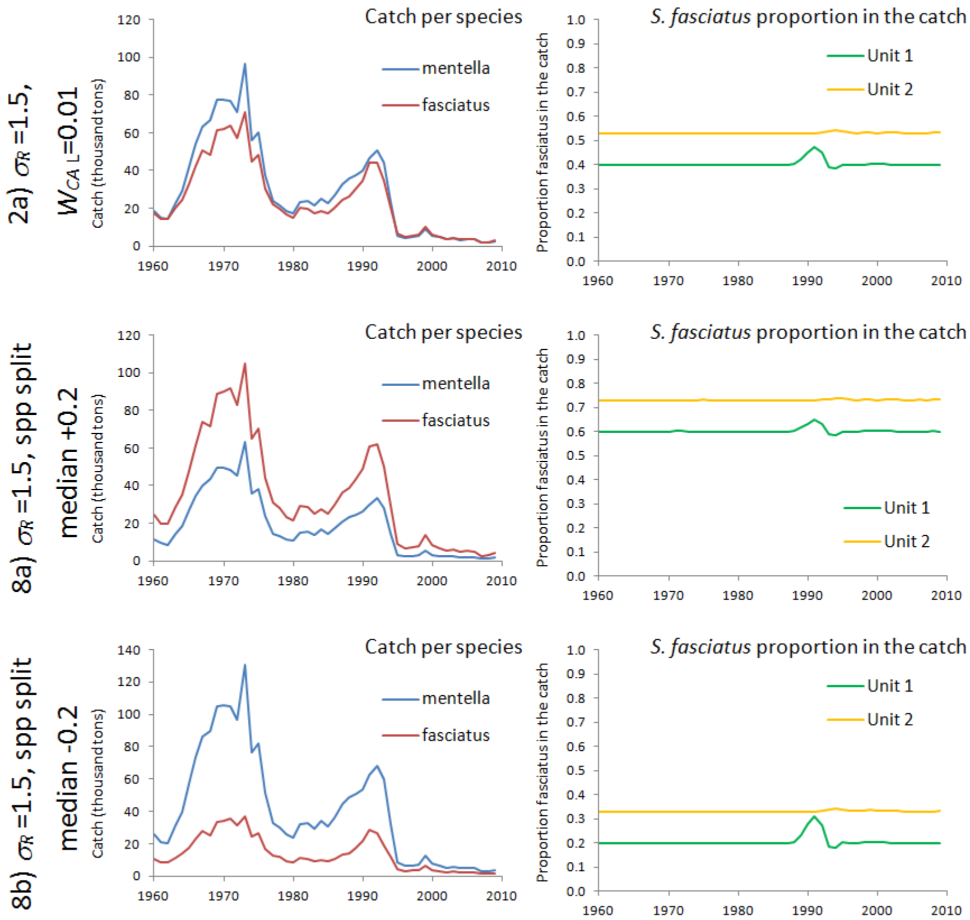

Figure 10: Catch trajectories by species, and estimated *S. fasciatus* proportion in the catch for **scenarios 2a, 8a and 8b**.

APPENDIX A – Data

Note: Units are throughout cm for length and yr for time.

Table A1: Total catch in kt of redfish (**all species combined**) in management Units 1 and 2.

Year	Unit 1	Unit 2	Year	Unit 1	Unit 2	Year	Unit 1	Unit 2
1960	12.83	23.29	1980	15.54	17.13	2000	1.12	10.29
1961	11.06	18.33	1981	22.05	21.75	2001	1.17	8.41
1962	7.15	21.30	1982	26.73	17.03	2002	1.22	6.45
1963	20.82	22.29	1983	24.97	13.47	2003	0.84	7.47
1964	30.52	23.19	1984	35.83	8.14	2004	0.94	5.89
1965	52.83	21.83	1985	28.33	11.49	2005	0.98	6.41
1966	67.96	28.39	1986	36.40	10.77	2006	0.69	6.48
1967	71.91	42.17	1987	43.45	13.96	2007	0.11	3.74
1968	95.26	20.17	1988	51.89	10.73	2008	0.42	3.72
1969	92.32	46.28	1989	52.48	15.39	2009	0.60	5.13
1970	90.50	49.41	1990	59.90	14.79			
1971	82.19	58.20	1991	67.53	23.21			
1972	82.55	45.20	1992	77.75	17.16			
1973	136.10	31.83	1993	51.09	27.43			
1974	67.08	34.04	1994	19.39	24.32			
1975	70.05	38.47	1995	0.05	12.24			
1976	44.38	23.71	1996	0.07	9.41			
1977	17.07	28.75	1997	0.04	9.94			
1978	14.93	26.55	1998	0.40	10.64			
1979	16.43	18.77	1999	1.11	17.90			

Table A2: Swept area assumed mature (i.e. >24cm for *S. mentella*, and >22cm for *S. fasciatus*) biomass estimates (in kt) and coefficients of variation (CVs) for ***S. mentella*** and ***S. fasciatus*** in Units 1 and 2, from McAllister and Duplisea (2012), Table 4.

	S. mentella				*S. fasciatus*			
Year	Unit 1	CV	Unit 2	CV	Unit 1	CV	Unit 2	CV
1990	443.012	0.272	-	-	267.287	-	-	-
1991	208.702	0.209	-	-	188.551	-	-	-
1992	147.726	0.206	-	-	208.862	-	-	-
1993	93.656	0.370	-	-	108.936	-	-	-
1994	55.785	0.185	-	-	70.997	-	-	-
1995	73.626	0.112	-	-	11.269	-	-	-
1996	59.242	0.175	-	-	10.183	-	-	-
1997	52.723	0.131	-	-	26.261	-	-	-
1998	26.391	0.186	-	-	47.989	-	-	-
1999	47.859	0.235	-	-	13.266	-	-	-
2000	49.549	0.122	223.464	0.233	19.033	-	119.324	0.498
2001	43.549	0.139	151.356	0.140	21.572	-	177.111	0.7
2002	67.468	0.797	-	-	13.495	-	-	-
2003	95.821	0.609	100.795	0.196	71.947	-	69.214	0.144
2004	23.963	0.219	-	-	14.234	-	-	-
2005	46.166	0.106	90.993	0.118	24.429	-	168.187	0.277
2006	25.042	0.125	-	-	37.737	-	-	-
2007	28.034	0.094	76.633	0.185	24.09	-	158.346	0.145
2008	79.371	0.462	-	-	52.778	-	-	-
2009	11.550	0.147	103.860	0.164	18.683	-	127.709	0.694

Table A3a: Commercial catch-at-length (number) for Atlantic redfish (**both species combined**) in Unit 1 (Daniel Duplisea, pers. commn)

Length	1981	1982	1983	1984	1985	1986	1987	1988	1989	1990	1991	1992	1993	1994	1999	2000	2001	2002	2003	2004	2005	2006	2007	2008	2009
10-	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
11	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
12	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
13	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
14	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0
15	0	0	0	25	9	5	34	24	4	18	5	20	69	8	3	0	1	2	1	0	2	0	0	0	0
16	0	5	12	78	15	85	23	11	4	33	56	108	1455	39	5	0	2	6	4	4	1	0	0	0	0
17	0	0	1	60	47	64	173	24	2	37	82	102	561	28	10	1	4	9	6	5	3	0	0	0	3
18	3	1	10	42	41	175	356	71	8	41	50	205	504	38	8	1	1	10	7	11	5	4	0	1	1
19	24	7	1	70	60	169	786	72	5	45	65	307	309	30	10	1	1	4	3	11	7	9	0	3	4
20	75	30	26	272	121	400	1378	189	30	22	50	313	227	46	14	3	7	5	4	14	10	28	0	1	6
21	157	73	78	429	330	790	2306	518	75	45	113	278	461	34	20	3	11	14	10	7	10	46	0	0	7
22	170	87	103	372	365	843	3988	1700	569	79	154	336	264	58	17	4	11	19	13	4	13	37	0	1	4
23	228	272	258	395	786	1232	5177	4603	1815	433	349	438	475	105	21	5	11	26	18	10	18	35	0	2	3
24	981	434	546	437	1354	2300	5919	10401	6025	1530	957	902	487	215	16	10	21	30	21	16	13	35	0	3	7
25	2987	1212	769	810	1620	3337	4300	15548	13354	5457	2220	1965	923	461	21	11	16	60	42	29	17	32	0	6	10
26	6335	2301	1338	1394	1600	4632	3519	14592	19007	15571	6771	6198	2684	949	24	15	25	50	35	31	22	80	0	5	27
27	10618	6007	2480	2286	1760	5415	3505	8669	19823	24636	15194	14648	6809	2001	37	21	47	60	42	37	42	103	0	8	29
28	10985	10642	5281	3829	2646	5341	3770	4675	13187	25363	22146	22907	15034	3773	51	27	69	66	47	58	45	128	1	16	36
29	7815	12281	8692	5891	3651	5150	4037	3825	7784	18290	20968	25930	19200	6063	86	74	102	50	35	38	40	106	2	18	55
30	4720	10130	9495	9479	5878	6821	4835	4659	6613	11038	16180	21442	17271	6834	192	129	167	69	49	56	63	144	1	27	52
31	2534	6544	8512	9733	6747	7889	6239	6345	6501	8279	11062	14932	11961	5340	216	196	225	132	93	94	69	121	2	34	51
32	2214	3939	6083	8760	7413	8111	7989	7396	7119	7951	8619	10861	7465	3946	282	283	258	185	130	111	88	102	4	36	60
33	2007	2778	3635	6919	6577	7587	8202	8843	7559	6839	7437	9490	5367	2901	252	304	270	227	160	140	122	92	10	37	60
34	1553	2045	2325	5168	5137	5996	8427	8570	6990	7107	7268	9020	4971	2314	244	221	265	256	180	180	139	99	13	48	74
35	950	1620	1803	3842	3473	4298	6745	7105	5347	5561	5970	7577	4405	2248	171	220	211	218	153	184	164	68	9	56	82
36	1154	1392	1437	3176	2524	3129	4972	4947	3997	4212	4080	6475	3481	1804	135	163	198	202	142	160	155	71	17	57	68
37	894	1286	1330	2531	1998	2182	3622	3794	2921	3020	3277	5148	3301	1070	93	103	114	141	100	136	145	57	19	53	54
38	743	632	910	2134	1783	1859	2974	2754	2053	2087	2367	3942	2529	814	70	73	75	100	71	80	114	42	15	47	67
39	640	445	580	1723	1057	1475	2051	2014	1465	1627	1746	3015	2124	634	48	49	36	67	47	63	86	25	15	39	46
40	622	338	403	1119	822	815	1489	1420	1004	988	1123	1977	1361	486	35	26	30	54	38	40	58	19	8	28	37
41	524	239	212	535	445	537	879	896	769	518	708	1334	810	173	20	25	9	39	27	18	33	11	6	23	27
42	120	133	100	367	353	356	663	561	439	275	390	951	551	118	11	9	3	18	12	10	22	4	4	14	12
43	25	81	83	114	219	198	323	363	271	200	224	534	295	45	5	13	3	14	10	8	13	3	5	7	7
44	2	84	46	66	188	127	168	249	119	100	108	320	155	29	2	8	2	9	6	8	10	2	1	7	8
45	8	72	25	59	58	44	77	91	47	38	73	128	122	12	1	5	1	3	2	1	3	3	2	7	3
46	0	54	37	28	23	53	47	43	27	15	33	76	49	8	0	3	1	1	1	2	2	1	1	2	3
47	8	89	51	12	20	26	28	26	9	15	12	29	13	5	0	1	0	2	1	2	2	1	1	5	1
48	1	81	31	7	11	7	23	26	1	2	2	15	3	0	0	2	1	1	1	1	1	0	0	2	1
49	1	67	43	10	16	4	1	6	5	0	0	0	1	2	0	1	0	1	1	0	0	0	0	2	0
50	0	95	13	14	14	2	6	1	0	16	0	6	8	0	0	1	3	0	0	0	0	0	0	0	1
51	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
52	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
53	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
54	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
55+	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0

Table A3b: Commercial catch-at-length (numbers) for Atlantic redfish (**both species combined**) for Unit 2 (Don Power, pers. commn)

Length	1995	1996	1997	1998	1999	2000	2001	2002	2003	2004	2009
10-	0	0	0	0	0	0	0	0	0	0	0
11	0	0	0	0	0	0	0	0	0	0	0
12	0	0	0	0	0	0	0	0	0	0	0
13	0	0	0	0	0	0	0	0	0	0	0
14	0	0	0	0	0	0	0	0	3	0	0
15	6	0	0	0	0	0	0	0	2	0	0
16	13	0	0	0	0	0	1	0	2	0	1
17	45	0	0	8	2	1	3	0	6	0	10
18	148	0	0	0	0	4	5	2	10	15	24
19	389	0	0	17	4	6	13	4	12	6	39
20	458	1	0	0	3	5	47	15	31	0	39
21	521	2	111	18	2	3	41	43	69	31	51
22	1104	1	259	17	14	9	101	65	100	52	22
23	1489	3	444	38	25	17	136	98	142	119	55
24	1123	5	628	49	50	14	356	129	232	156	141
25	1279	3	924	157	97	15	521	178	342	187	243
26	1708	3	483	273	132	17	745	236	445	264	519
27	1966	55	667	346	156	31	640	344	530	330	660
28	2592	323	739	487	226	78	643	343	531	267	923
29	3191	1266	1059	1059	593	212	565	298	543	302	944
30	3364	2321	1366	1793	1127	425	576	454	636	376	1064
31	3434	2756	1435	2471	1918	731	751	529	787	473	1001
32	2746	2817	1995	2886	2455	1138	914	632	1098	882	1082
33	1733	2106	1779	2562	2234	1244	1063	730	1299	1168	1007
34	1282	1421	1780	1958	2113	1100	998	657	1414	1405	1080
35	842	1199	1527	1599	1414	851	879	501	1257	1330	813
36	649	855	1063	1036	924	592	704	475	1053	1184	726
37	410	676	852	831	619	359	467	328	842	888	576
38	281	515	543	672	467	306	296	196	499	561	401
39	212	428	652	462	384	219	214	130	300	405	395
40	198	320	268	342	252	129	155	94	170	116	170
41	106	214	324	198	179	75	90	55	106	93	108
42	66	141	131	107	93	53	94	51	83	33	30
43	41	90	106	73	63	24	41	40	79	22	16
44	34	41	82	32	38	18	30	31	58	9	6
45	18	25	38	16	20	3	23	26	55	5	2
46	13	6	35	7	6	4	11	18	39	6	4
47	8	8	0	3	1	1	8	19	34	2	0
48	0	2	1	2	0	0	0	8	23	0	1
49	0	0	1	0	0	0	5	4	14	0	0
50	7	0	0	0	0	0	5	2	14	0	1
51	0	0	0	1	0	0	2	1	6	0	0
52	0	0	0	0	0	0	1	1	10	0	0
53	1	0	0	0	0	0	1	0	5	0	0
54	0	0	0	0	0	0	0	1	4	0	0
55+	0	0	0	0	0	0	8	0	4	0	0

Table A4a: Survey catch-at-length (numbers) for ***S. mentella*** for Unit 1 and Unit 2 (Daniel Duplisea, pers. commn)

	Unit 1																					Unit 2					
Length	1990	1991	1992	1993	1994	1995	1996	1997	1998	1999	2000	2001	2002	2003	2004	2005	2006	2007	2008	2009	2010	2000	2001	2003	2005	2007	2009
1	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
2	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
3	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.003	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
4	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.015	0.000	0.000	0.000	0.000	0.000	0.001	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
5	0.001	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.012	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.026	0.004	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
6	0.006	0.003	0.011	0.000	0.000	0.000	0.000	0.000	0.016	0.003	0.002	0.000	0.000	0.000	0.000	0.000	0.000	0.138	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
7	0.573	0.165	0.140	0.017	0.000	0.019	0.056	0.015	0.058	0.006	0.030	0.011	0.000	0.000	0.000	0.715	0.002	0.002	0.006	0.000	0.002	0.004	0.000	0.054	0.378	0.032	0.092
8	23.080	1.628	0.195	0.043	0.000	0.159	0.266	0.025	0.458	0.108	0.634	0.143	0.012	0.031	0.000	2.852	0.006	0.047	0.035	0.011	0.020	0.000	0.778	0.266	7.180	0.073	0.237
9	72.781	2.569	0.682	0.345	0.007	0.541	1.229	0.196	0.957	0.582	1.715	0.353	0.154	0.176	0.020	12.212	0.030	0.229	0.143	0.009	0.027	0.000	3.738	0.301	15.815	0.059	0.430
10	21.101	19.418	0.556	0.190	0.019	0.251	0.812	0.246	1.556	0.644	0.627	0.343	0.322	0.371	0.072	10.155	0.502	0.489	0.099	0.009	0.023	0.292	17.513	0.147	9.910	0.182	0.280
11	0.658	65.248	1.751	0.138	0.141	0.026	0.261	0.256	0.344	0.554	0.160	0.090	0.296	0.143	0.036	1.753	3.453	0.043	0.049	0.005	0.024	0.255	19.679	0.235	2.382	0.017	0.580
12	0.674	118.381	7.019	0.323	0.545	0.067	0.481	0.576	0.228	1.261	0.626	0.566	0.584	0.207	0.083	0.132	8.219	0.232	0.109	0.064	0.078	0.497	4.630	1.020	1.761	0.415	0.717
13	1.185	62.509	13.365	1.065	1.043	0.191	0.772	0.942	0.525	2.870	1.714	1.148	0.443	1.229	0.160	0.097	5.164	3.995	0.099	0.136	0.087	0.634	8.134	1.412	1.013	2.720	2.416
14	1.888	6.927	13.987	0.888	0.961	0.282	0.517	1.080	0.565	2.434	2.182	0.894	0.295	2.152	0.219	0.173	0.733	14.497	0.070	0.127	0.081	1.042	8.960	2.873	1.137	16.205	5.122
15	3.282	1.927	6.140	1.593	1.005	0.462	0.171	0.676	0.809	1.013	1.661	0.373	0.235	1.610	0.178	0.163	0.036	35.305	0.112	0.056	0.191	2.248	8.492	3.155	0.975	56.719	5.859
16	4.975	2.194	0.709	2.040	1.373	0.680	0.220	0.456	0.787	0.452	1.378	0.693	0.395	0.909	0.302	0.250	0.030	37.413	0.247	0.053	0.250	3.409	12.158	2.596	2.309	26.708	3.381
17	7.019	2.617	0.573	1.827	1.360	1.200	0.365	0.605	0.664	0.478	2.115	0.939	0.663	0.722	0.880	0.267	0.066	13.978	0.606	0.090	0.385	4.677	19.240	2.388	5.351	11.535	3.682
18	5.372	2.274	0.786	0.564	0.886	0.905	0.349	0.531	0.633	0.392	1.844	0.688	0.409	0.346	1.154	0.338	0.117	1.862	0.731	0.106	0.296	6.096	22.243	1.538	9.410	3.591	5.453
19	1.721	1.547	0.683	0.375	0.609	0.724	0.555	0.349	0.439	0.375	0.697	0.766	0.471	0.365	0.816	0.393	0.176	0.131	0.334	0.112	0.370	8.379	17.505	1.480	13.214	1.267	4.837
20	0.650	0.747	0.553	0.169	0.341	0.625	0.660	0.243	0.301	0.240	0.396	0.692	0.409	0.529	0.474	0.530	0.188	0.163	0.284	0.140	0.360	5.508	13.945	2.193	14.337	1.743	3.793
21	0.592	0.767	0.615	0.258	0.128	0.331	0.554	0.186	0.148	0.297	0.380	0.763	0.359	0.559	0.276	0.647	0.339	0.217	0.204	0.129	0.609	3.593	16.192	1.757	12.097	1.623	1.843
22	0.844	0.505	0.694	0.244	0.179	0.254	0.481	0.219	0.185	0.287	0.258	0.391	0.352	0.432	0.204	0.750	0.121	0.273	0.406	0.060	0.512	2.328	11.980	2.543	9.456	1.450	0.487
23	1.023	0.558	1.201	0.211	0.140	0.193	0.362	0.252	0.128	0.205	0.250	0.184	0.290	0.483	0.207	0.491	0.186	0.244	0.752	0.032	1.460	1.694	9.932	2.767	6.705	2.069	0.394
24	2.176	0.790	1.582	0.155	0.159	0.194	0.211	0.168	0.080	0.148	0.202	0.046	0.240	1.572	0.218	0.381	0.085	0.215	2.186	0.016	1.415	2.376	12.382	2.641	4.664	1.911	0.650
25	5.389	1.281	1.701	0.220	0.224	0.037	0.150	0.160	0.096	0.140	0.216	0.110	0.187	1.431	0.220	0.251	0.109	0.194	2.819	0.029	2.994	3.038	12.137	2.793	3.870	2.733	0.484
26	11.972	2.455	2.594	0.419	0.387	0.134	0.093	0.159	0.157	0.110	0.165	0.133	0.089	3.019	0.148	0.223	0.092	0.178	3.627	0.063	3.644	3.232	12.542	2.001	4.293	3.559	0.847
27	22.362	6.029	5.490	0.929	0.676	0.220	0.230	0.073	0.102	0.166	0.172	0.164	0.083	4.367	0.237	0.319	0.095	0.220	5.616	0.044	4.270	2.786	9.966	2.590	3.557	3.331	0.953
28	35.122	11.062	9.966	2.799	0.876	0.740	0.366	0.275	0.085	0.129	0.188	0.200	0.069	7.265	0.278	0.268	0.043	0.273	5.095	0.034	5.037	2.553	8.449	1.702	3.018	2.863	1.172
29	33.783	14.903	11.077	4.878	1.973	2.104	0.780	0.576	0.189	0.238	0.278	0.268	0.089	8.706	0.209	0.241	0.101	0.241	4.996	0.040	4.506	4.528	8.584	1.646	2.446	1.868	1.554
30	22.904	13.858	10.435	7.867	3.053	3.476	1.790	1.240	0.360	0.578	0.382	0.258	0.422	5.650	0.212	0.264	0.062	0.192	3.299	0.093	4.712	7.217	8.155	2.714	3.262	2.289	2.841
31	14.262	10.580	7.241	9.038	2.916	4.024	2.549	2.487	0.777	1.202	0.815	0.430	0.632	2.227	0.304	0.390	0.118	0.228	0.920	0.143	1.917	12.009	9.136	3.365	3.871	2.502	3.326
32	8.846	6.101	5.660	5.922	2.569	3.325	3.001	2.601	1.366	1.700	1.089	1.001	1.517	2.620	0.305	0.776	0.151	0.224	0.555	0.137	0.825	21.620	10.624	6.370	6.253	4.080	4.728
33	6.960	4.691	3.312	4.114	1.609	2.736	2.632	2.840	1.261	2.074	1.870	1.188	2.970	1.256	0.407	0.944	0.382	0.368	0.759	0.188	0.612	24.614	12.358	7.278	6.460	4.929	6.776
34	8.007	3.947	3.245	3.038	1.585	1.873	2.272	1.966	0.993	2.406	1.636	1.625	3.792	1.118	0.571	1.381	0.480	0.509	1.423	0.236	1.482	26.932	13.032	9.733	7.937	6.387	8.410
35	9.197	4.035	2.971	2.090	1.398	1.872	1.618	1.731	1.109	1.753	2.084	1.785	2.915	1.391	0.705	1.600	0.641	0.606	1.418	0.276	0.577	24.998	11.736	9.642	8.816	6.568	10.620
36	10.800	4.164	2.213	1.833	1.263	2.000	1.233	1.364	0.674	1.455	1.796	1.678	2.795	1.714	0.681	1.429	0.882	0.781	1.677	0.415	0.695	17.598	10.802	9.371	8.053	7.368	10.420
37	7.912	3.444	2.214	1.230	1.088	1.223	1.174	1.064	0.522	1.051	1.556	1.375	2.152	1.777	0.616	1.631	0.929	0.744	1.598	0.388	0.818	11.117	7.875	7.194	7.006	6.275	9.500
38	7.113	3.141	1.378	1.139	0.910	1.174	0.950	0.805	0.545	0.709	1.016	1.011	1.218	1.324	0.550	1.133	0.754	0.730	1.482	0.244	0.305	9.737	5.179	5.932	5.377	5.458	9.018
39	6.422	1.940	1.064	0.707	0.747	0.760	0.627	0.725	0.299	0.459	0.801	0.639	0.950	1.241	0.326	0.851	0.557	0.564	0.986	0.266	0.421	4.607	3.090	3.289	3.134	3.411	6.115
40	2.982	1.797	0.821	0.391	0.508	0.734	0.766	0.388	0.152	0.485	0.688	0.455	0.450	0.963	0.267	0.708	0.424	0.560	0.707	0.207	0.248	3.602	2.641	2.315	1.960	2.353	3.537
41	3.632	1.595	0.642	0.191	0.279	0.466	0.349	0.263	0.142	0.170	0.417	0.361	0.411	0.592	0.321	0.466	0.271	0.473	0.456	0.105	0.294	2.073	1.998	1.384	1.303	1.047	1.944
42	1.361	0.839	0.349	0.131	0.204	0.263	0.270	0.221	0.099	0.295	0.173	0.247	0.282	0.200	0.186	0.281	0.211	0.244	0.347	0.092	0.237	2.025	1.222	1.293	0.617	0.723	1.435
43	0.871	0.603	0.226	0.087	0.250	0.115	0.200	0.113	0.102	0.193	0.190	0.131	0.102	0.186	0.094	0.176	0.151	0.191	0.200	0.092	0.148	2.025	0.747	0.576	0.369	0.341	0.732
44	0.885	0.391	0.089	0.116	0.150	0.130	0.162	0.075	0.059	0.108	0.287	0.110	0.066	0.119	0.078	0.149	0.089	0.081	0.152	0.050	0.098	1.599	0.499	0.559	0.308	0.205	0.302
45	0.243	0.281	0.043	0.041	0.016	0.095	0.046	0.052	0.039	0.079	0.062	0.068	0.062	0.132	0.091	0.100	0.074	0.046	0.216	0.014	0.080	0.762	0.141	0.371	0.129	0.117	0.388
46	0.069	0.177	0.069	0.024	0.019	0.088	0.028	0.056	0.005	0.027	0.026	0.055	0.036	0.021	0.042	0.038	0.047	0.062	0.040	0.014	0.020	0.413	0.141	0.197	0.052	0.063	0.100
47	0.020	0.117	0.030	0.000	0.036	0.053	0.012	0.005	0.000	0.028	0.038	0.012	0.058	0.021	0.022	0.055	0.011	0.037	0.028	0.000	0.059	0.360	0.066	0.109	0.061	0.052	0.116
48	0.024	0.012	0.000	0.000	0.010	0.019	0.000	0.025	0.027	0.014	0.057	0.025	0.027	0.003	0.009	0.072	0.011	0.011	0.000	0.002	0.026	0.259	0.084	0.074	0.057	0.015	0.034
49	0.002	0.105	0.003	0.000	0.005	0.000	0.000	0.017	0.000	0.000	0.000	0.039	0.000	0.000	0.018	0.046	0.000	0.000	0.006	0.002	0.000	0.104	0.041	0.068	0.009	0.000	0.017
50	0.013	0.000	0.000	0.008	0.005	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.019	0.022	0.000	0.003	0.000	0.000	0.000	0.094	0.038	0.054	0.000	0.000	0.014
51	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.007	0.009	0.001	0.000	0.000	0.000	0.000	0.000	0.021	0.026	0.043	0.000	0.000	0.013
52	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.015	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.017	0.000	0.000	0.000	0.000	0.000	0.021	0.057	0.040	0.000	0.000	0.000
53	0.007	0.000	0.000	0.000	0.005	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.023	0.024	0.000	0.000	0.000
54	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.009	0.000	0.000	0.000	0.000	0.000	0.000	0.012	0.018	0.000	0.000	0.000
55	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.004	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.006	0.000	0.000	0.000
56	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.012	0.004	0.000	0.000	0.000	0.000	0.008	0.000	0.029	0.000	0.000	0.000	0.000
57	0.000	0.007	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
58	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
59	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.029	0.000	0.000	0.000	0.000

Table A4b: Survey catch-at-length (numbers) for ***S. fasciatus*** for Unit 1 and Unit 2 (Daniel Duplisea, pers. commn)

	Unit 1																					Unit 2					
Length	1990	1991	1992	1993	1994	1995	1996	1997	1998	1999	2000	2001	2002	2003	2004	2005	2006	2007	2008	2009	2010	2000	2001	2003	2005	2007	2009
1	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
2	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
3	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
4	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.013	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
5	0.011	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.008	0.000	0.000	0.000	0.000	0.000	0.000	0.002	0.017	0.132	0.002	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
6	0.020	0.033	0.061	0.000	0.000	0.017	0.019	0.000	0.219	0.007	0.002	0.000	0.000	0.000	0.028	0.009	0.000	0.310	0.036	0.014	0.000	0.000	0.000	0.000	0.187	0.000	0.000
7	4.208	0.576	0.600	0.075	0.000	0.275	0.360	0.468	3.187	0.053	0.313	0.282	0.010	0.027	0.174	0.735	0.010	0.125	0.479	0.745	0.192	0.060	0.000	0.010	3.499	0.152	0.080
8	119.052	4.755	0.668	0.205	0.018	0.952	1.093	0.855	12.224	0.279	3.789	1.488	0.038	0.412	0.395	126.070	0.325	4.052	1.702	5.668	1.338	0.071	0.290	0.391	61.827	0.583	0.429
9	289.666	9.383	1.123	0.467	0.080	2.150	1.650	0.729	8.141	1.212	7.785	6.190	0.328	0.375	0.674	552.076	1.819	42.487	2.351	10.414	2.482	0.072	1.470	0.334	140.467	0.911	0.767
10	63.496	66.314	1.364	0.354	0.294	0.781	1.085	1.174	3.517	2.777	4.015	11.232	1.152	0.533	0.900	192.448	9.015	11.445	3.149	6.285	2.596	0.331	6.210	0.169	74.066	1.102	0.746
11	1.562	206.499	6.053	0.320	0.380	0.276	0.808	2.295	1.831	5.628	1.740	4.151	1.990	1.009	0.549	11.096	24.348	0.766	6.376	0.846	3.757	0.820	6.069	0.232	12.727	0.435	0.788
12	1.377	355.845	21.390	0.518	0.912	0.435	0.796	2.851	1.701	7.587	3.656	1.563	3.618	2.620	1.198	0.933	119.218	3.765	28.003	1.256	9.753	0.839	1.842	0.997	6.901	9.796	1.784
13	2.370	179.842	41.364	0.955	0.998	0.529	0.855	2.277	2.011	6.309	6.902	2.235	6.596	4.293	1.737	1.055	176.801	29.879	16.814	2.390	10.983	0.985	2.900	1.598	5.992	59.957	4.698
14	3.969	20.317	42.606	2.461	1.192	0.589	0.526	1.549	2.186	4.678	10.968	2.063	5.311	8.878	2.322	2.119	46.190	81.378	6.749	3.625	5.390	1.714	3.256	2.563	7.096	182.403	9.255
15	7.191	7.285	19.065	5.797	2.055	0.766	0.517	0.958	2.961	3.155	10.896	1.818	1.586	10.177	3.291	1.777	7.487	130.437	5.685	5.789	2.875	3.055	4.895	3.844	6.889	240.143	14.248
16	9.977	7.241	1.347	8.428	2.467	0.698	0.427	0.616	2.381	2.369	4.770	2.364	1.000	8.084	3.315	1.793	1.612	70.727	10.320	6.111	2.951	3.437	6.823	4.002	10.074	120.990	16.145
17	14.364	7.989	1.262	6.582	2.539	0.927	0.462	0.450	1.327	1.755	3.346	2.148	1.181	4.784	3.530	1.420	0.552	19.580	10.806	2.572	2.959	5.827	10.228	4.435	22.083	37.332	46.546
18	11.123	6.566	1.728	2.453	2.002	0.700	0.460	0.424	1.099	1.157	2.710	1.425	1.051	2.218	3.640	1.875	1.150	3.256	9.988	3.188	3.149	7.767	12.458	5.120	37.597	15.961	84.143
19	3.876	4.305	1.217	0.856	0.893	0.552	0.694	0.469	0.846	0.778	1.246	1.011	0.840	1.465	2.174	2.044	1.229	1.907	3.692	3.360	2.487	9.533	11.138	6.331	50.166	10.533	83.373
20	1.582	2.148	1.120	0.600	0.440	0.500	0.560	0.450	1.636	0.401	1.009	0.694	0.879	1.103	1.263	2.018	1.348	1.752	1.369	2.338	2.149	9.798	10.626	8.022	50.734	13.346	59.069
21	1.222	1.963	1.313	0.813	0.185	0.367	0.630	0.366	1.406	0.346	0.390	0.559	0.697	0.964	0.596	1.365	1.422	2.194	0.635	1.716	1.516	8.069	10.094	10.871	37.204	10.305	29.014
22	1.524	1.307	1.810	2.039	0.219	0.356	0.376	0.352	4.929	0.328	0.582	0.582	0.685	1.039	0.563	1.006	1.468	1.044	0.521	1.205	1.321	6.802	7.924	13.986	27.164	11.562	11.604
23	1.753	1.631	3.170	4.818	0.389	0.264	0.239	0.251	3.871	0.447	0.310	0.336	0.407	0.965	0.612	0.594	2.151	0.776	0.544	0.664	0.862	6.001	10.150	10.622	19.816	12.633	5.769
24	3.181	2.298	4.075	8.224	0.603	0.250	0.185	0.347	5.376	0.381	0.440	0.333	0.350	1.454	0.781	0.453	1.629	0.802	0.823	0.448	0.418	7.882	25.295	9.675	18.605	12.181	15.870
25	6.559	3.464	4.070	7.765	0.764	0.346	0.130	0.264	3.136	0.336	0.321	0.307	0.556	1.779	0.813	0.453	2.209	0.480	0.915	0.536	0.374	9.976	37.601	8.813	16.561	16.012	20.152
26	13.683	5.013	5.560	7.992	1.508	0.299	0.183	0.284	2.974	0.374	0.221	0.376	0.286	2.750	0.930	0.658	2.851	0.287	1.383	0.746	0.660	11.383	65.737	10.033	15.436	19.007	17.919
27	22.599	9.103	9.703	9.571	2.167	0.237	0.152	0.343	2.477	0.487	0.278	0.294	0.500	3.749	0.984	0.764	2.432	0.507	1.244	0.675	0.739	10.200	47.704	8.738	12.501	17.462	16.557
28	28.886	13.078	14.215	7.937	1.545	0.233	0.159	0.703	1.298	0.424	0.213	0.202	0.383	5.810	0.628	0.630	1.956	0.431	1.260	0.626	0.807	8.029	32.294	7.496	8.120	13.448	14.291
29	22.941	15.507	14.714	5.745	2.436	0.345	0.406	0.930	2.401	0.437	0.346	0.295	0.398	7.156	0.796	0.582	1.638	0.451	1.489	0.773	0.915	7.236	23.948	7.172	4.922	7.557	10.712
30	13.174	12.140	12.670	6.036	3.072	0.300	0.492	1.216	2.331	0.421	0.473	0.314	0.441	5.158	0.565	0.549	1.414	0.341	2.175	0.610	0.387	7.494	26.153	6.663	5.574	8.138	9.081
31	7.520	8.361	9.134	4.958	2.319	0.348	0.404	1.464	1.920	0.276	0.446	0.665	0.370	1.908	0.517	0.558	0.856	0.265	1.915	0.624	0.496	7.481	10.925	5.396	4.168	6.666	8.268
32	4.622	5.607	8.374	2.606	2.708	0.258	0.380	1.212	0.572	0.307	0.510	0.826	0.463	2.306	0.219	0.573	0.731	0.255	2.491	0.485	0.397	8.830	9.416	4.748	5.852	7.385	7.008
33	3.425	3.643	4.935	1.636	2.397	0.195	0.310	1.084	0.666	0.358	0.661	0.885	0.258	0.802	0.156	0.511	0.538	0.335	2.395	0.386	0.214	7.006	3.172	2.908	5.949	7.342	5.370
34	4.006	2.716	3.766	0.963	1.866	0.230	0.196	0.887	0.484	0.373	0.505	0.695	0.311	0.685	0.051	0.450	0.439	0.351	1.154	0.319	0.379	7.938	2.791	3.133	6.746	6.537	5.569
35	3.331	2.503	3.208	0.620	1.478	0.280	0.220	0.821	0.808	0.313	0.465	0.700	0.342	0.459	0.105	0.509	0.284	0.381	1.572	0.204	0.578	8.769	1.635	2.809	6.516	4.566	5.133
36	3.614	2.241	1.655	0.342	1.425	0.206	0.175	0.418	0.291	0.283	0.524	0.476	0.311	0.522	0.032	0.284	0.330	0.424	1.044	0.198	0.507	5.125	1.509	2.184	5.120	3.688	4.370
37	2.555	1.655	2.130	0.312	1.180	0.172	0.137	0.198	0.228	0.290	0.363	0.591	0.202	0.469	0.091	0.289	0.341	0.318	0.748	0.238	0.436	5.039	1.077	1.522	4.309	3.297	4.452
38	2.357	1.749	0.907	0.162	1.056	0.200	0.134	0.110	0.196	0.092	0.351	0.310	0.132	0.677	0.047	0.281	0.279	0.281	0.497	0.145	0.197	3.786	0.376	1.311	3.195	2.842	3.351
39	1.990	1.188	1.056	0.072	0.771	0.097	0.097	0.124	0.160	0.101	0.182	0.165	0.146	0.527	0.027	0.143	0.159	0.262	0.429	0.157	0.179	2.300	0.244	0.943	1.678	1.846	2.361
40	1.165	0.970	0.675	0.054	0.414	0.100	0.074	0.121	0.091	0.079	0.152	0.158	0.055	0.409	0.023	0.178	0.169	0.148	0.417	0.135	0.141	1.961	0.242	0.640	1.219	1.615	1.535
41	1.051	0.717	0.278	0.041	0.183	0.098	0.042	0.029	0.054	0.049	0.116	0.114	0.057	0.151	0.036	0.137	0.112	0.103	0.250	0.091	0.226	0.867	0.122	0.383	0.603	0.715	0.805
42	0.500	0.381	0.180	0.041	0.084	0.065	0.027	0.035	0.041	0.031	0.067	0.045	0.025	0.113	0.067	0.064	0.086	0.074	0.110	0.061	0.091	1.301	0.089	0.278	0.581	0.619	0.427
43	0.322	0.224	0.105	0.008	0.096	0.018	0.020	0.045	0.029	0.021	0.056	0.048	0.006	0.026	0.028	0.032	0.052	0.046	0.108	0.054	0.056	1.047	0.037	0.162	0.223	0.302	0.268
44	0.242	0.190	0.055	0.016	0.038	0.029	0.012	0.017	0.027	0.013	0.037	0.005	0.007	0.033	0.006	0.082	0.016	0.021	0.037	0.019	0.027	0.790	0.038	0.135	0.154	0.187	0.168
45	0.095	0.116	0.021	0.001	0.017	0.007	0.002	0.014	0.013	0.022	0.018	0.029	0.008	0.024	0.017	0.037	0.012	0.121	0.020	0.012	0.012	0.357	0.005	0.107	0.092	0.083	0.122
46	0.037	0.054	0.029	0.000	0.013	0.008	0.000	0.002	0.000	0.005	0.005	0.004	0.000	0.004	0.004	0.017	0.050	0.019	0.024	0.008	0.012	0.072	0.009	0.059	0.015	0.075	0.038
47	0.011	0.026	0.012	0.000	0.004	0.002	0.008	0.000	0.007	0.001	0.006	0.005	0.000	0.000	0.002	0.049	0.000	0.000	0.003	0.000	0.014	0.073	0.006	0.042	0.032	0.022	0.041
48	0.006	0.006	0.000	0.000	0.000	0.000	0.000	0.000	0.006	0.001	0.002	0.002	0.000	0.027	0.002	0.139	0.016	0.003	0.000	0.002	0.011	0.141	0.010	0.043	0.021	0.008	0.071
49	0.007	0.020	0.001	0.000	0.007	0.000	0.000	0.013	0.008	0.000	0.000	0.000	0.000	0.000	0.002	0.045	0.000	0.000	0.001	0.005	0.009	0.033	0.009	0.035	0.007	0.003	0.006
50	0.001	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.004	0.000	0.000	0.000	0.000	0.000	0.002	0.049	0.000	0.007	0.066	0.000	0.000	0.000	0.007	0.032	0.000	0.000	0.011
51	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.007	0.000	0.000	0.000	0.000	0.000	0.002	0.000	0.000	0.000	0.000	0.000	0.000	0.012	0.015	0.021	0.000	0.010	0.012
52	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.001	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.039	0.000	0.000	0.000	0.000	0.000	0.024	0.002	0.016	0.000	0.000	0.000
53	0.015	0.000	0.000	0.000	0.007	0.000	0.000	0.000	0.004	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.012	0.013	0.012	0.000	0.000	0.000
54	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.019	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.013	0.000	0.000	0.000
55	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.010	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.004	0.000	0.000	0.000
56	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.002	0.010	0.000	0.000	0.000	0.000	0.001	0.000	0.001	0.000	0.000	0.000	0.000
57	0.000	0.015	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
58	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
59	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.001	0.000	0.000	0.000	0.000

Table A5: Life history parameters assumed for *S. mentella* and *S. fasciatus*.

S. mentella				
M	0.1			McAllister and Duplisea (2012)
h	0.67			McAllister and Duplisea (2012)
Length-at-maturity	24			Knife-edged, Don Power, pers. commn
Fraction of M that occurs before spawning (M^s)	0.25			
	L_{inf}	κ	t_0	
Length-at-age	35.81	0.1458	0	$L_a = L_{\inf}\left(1 - e^{-\kappa(a-t_0)}\right)$, Campana, pers. commn
	α	β		
Weight-at-age	0.00944	3.107		$W_a = \alpha(L_a)^\beta$, McAllister and Duplisea (2012)
S. fasciatus				
M	0.125			McAllister and Duplisea (2012)
h	0.67			McAllister and Duplisea (2012)
Length-at-maturity	22			Knife-edged, Don Power, pers. commn
Fraction of M that occurs before spawning (M^s)	0.25			
	L_{inf}	κ	t_0	
Length-at-age	31.88	0.2213	0	$L_a = L_{\inf}\left(1 - e^{-\kappa(a-t_0)}\right)$, Campana, pers. commn
	α	β		
Weight-at-age	0.01106	3.08		$W_a = \alpha(L_a)^\beta$, McAllister and Duplisea (2012)

Appendix B - The Statistical Catch-At-Length Model

The model used for these assessments is a Statistical Catch-At-Length (SCAL) model. The approach used involves the construction of an age-structured model of the population dynamics and fitting it to the available abundance indices by maximising the likelihood function. The general specifications of the model and its equations are described below, followed by details of the contributions to the (penalised) log-likelihood function from the different sources of data available and assumptions concerning the stock-recruitment relationship. Quasi-Newton minimization is used to minimize the total negative log-likelihood function (the package AD Model Builder™, Otter Research, Ltd is used for this purpose).

B.1. Population dynamics

B.1.1 Numbers-at-age

The resource dynamics of the two populations (*S. mentella* and *S. fasciatus*) are modelled by the following set of population dynamics equations:

$$N_{s,y+1,0} = R_{s,y+1} \qquad \text{(B1)}$$

$$N_{s,y+1,a+1} = N_{s,y,a}\, e^{-Z_{s,y,a}} \qquad \text{for } 0 \le a \le m_s - 2 \qquad \text{(B2)}$$

$$N_{s,y+1,m_s} = N_{y,m_s-1}\, e^{-Z_{s,y,m_s-1}} + N_{y,m_s}\, e^{-Z_{s,y,m_s}} + \qquad \text{(B3)}$$

where

$N_{s,y,a}$ is the number of species *s* and age *a* at the start of year *y* (which refers to a calendar year),

$R_{s,y}$ is the recruitment (number of 0-year-old fish) of species *s* at the start of year *y*,

m_s is the maximum age considered (taken to be a plus-group) for species *s*, m_s=20,

$Z_{s,y,a} = \sum_u F_{s,u,y} S_{s,u,y,a} + M_{s,a}$ is the total mortality in year *y* on fish of species *s* and age *a*, and

$M_{s,a}$ denotes the natural mortality rate for fish of species *s* of age *a*,

$F_{s,u,a}$ is the fishing mortality of a fully selected age class of species *s*, for Unit *u* in year *y*,

$S_{s,y,a}$ is the commercial selectivity (i.e. combination of availability and vulnerability to fishing gear) of species *s* at age *a* and in year *y*; when $S_{s,y,a}$ = 1, the age-class *a* is said to be fully selected,

Selectivity is estimated as a function of length and then converted to selectivity-at-age:

$$S_{s,u,y,a} = \sum_l S_{s,u,y,l} A_{s,a,l} \qquad \text{(B4)}$$

where $A_{s,a,l}$ is the proportion of fish of species *s* and age *a* that fall in the length group *l* (i.e., $\sum_l A_{s,a,l} = 1$ for all ages).

The matrix $A_{s,a,l}$ is calculated under the assumption that length-at-age is normally distributed about a mean given by the von Bertalanffy equation, i.e. (omitting the species subscript *s*):

$$L_a \sim N\left[L_\infty\left(1-e^{-\kappa(a-t_o)}\right);\theta_a^2\right] \qquad \text{(B5)}$$

where

θ_a is the standard deviation of length-at-age *a*, which is taken as proportional to the expected length-at-age *a*, i.e.:

$$\theta_a = \beta^* L_\infty\left(1-e^{-\kappa(a-t_o)}\right) \qquad \text{(B6)}$$

with β^* an estimable parameter (taken to be the same for both species).

B.1.2. Recruitment

The number of recruits of each species at the start of year *y* is assumed to be related to the spawning stock size (i.e. the biomass of mature fish) by a Beverton-Holt stock-recruitment relationship (Beverton and Holt, 1957), parameterised in terms of the "steepness" of the stock-recruitment relationship, h_s, and the pre-exploitation equilibrium spawning biomass, K_s^{sp}, and recruitment, $R_{s,0}$ and allowing for annual fluctuation about the deterministic relationship:

$$R_{s,y} = \frac{4h_s R_{s,0} B_{s,y}^{sp}}{K_s^{sp}(1-h_s)+(5h_s-1)B_{s,y}^{sp}} e^{(\varsigma_{s,y}-\sigma_R^2/2)} \qquad \text{(B7)}$$

where

$\varsigma_{s,y}$ reflects fluctuation about the expected recruitment for species *s* for year *y*, which is assumed to be normally distributed with standard deviation σ_R (which is input in the applications considered here); these residuals are treated as estimable parameters in the model fitting process.

$B_{s,y}^{sp}$ is the spawning biomass of species *s* at the start of year *y*, computed as:

$$B_{s,y}^{sp} = \sum_{a=1}^{m_s} f_{s,a} w_{s,a}^{strt} N_{s,y,a} e^{-M_{s,a}M_s^{sp}} \qquad \text{(B8)}$$

where

$w_{s,a}^{strt}$ is the mass of fish of species *s* and age *a* during spawning,

$f_{s,a}$ is the proportion of fish of species *s* and age *a* that are mature

M_s^{sp} is the fraction of mortality that occurs before spawning for species *s* ($M_s^{sp}=0.25$).

In the fitting procedure, K_s^{sp} are estimated while h_s have thus far been fixed at 0.67 for consistency with McAllister and Duplisea (2011).

B.1.3. Total catch and catches-at-age

The catch by mass for species *s* in Unit *u*, in year *y* is given by:

$$C_{s,u,y} = \sum_{a=0}^{m} \tilde{w}_{s,a}^{mid} C_{s,u,y,a} = \sum_{a=0}^{m} \tilde{w}_{s,y,a}^{mid} F_{s,u,y} S_{s,u,y,a} N_{s,y,a}\left(1-e^{-Z_{s,y,a}}\right)\Big/ Z_{s,y,a} \qquad \text{(B9)}$$

where

$C_{s,u,y,a}$ is the catch-at-age, i.e. the number of fish of species *s* and age *a*, caught in year *y* in Unit *u,*

$\tilde{w}^{mid}_{s,y,a}$ is the selectivity-weighted mid-year weight-at-age *a* for species *s* landed in year *y*, and

$$\tilde{w}^{\mathrm{mid}}_{s,y,a} = \sum_{l} S_{s,y,l} w_{s,l} A_{s,a,l} \Big/ \sum_{l} S_{s,y,l} A_{s,a,l} \qquad \text{(B10)}$$

with

$w_{s,l}$ being the weight of fish of species *s* and length *l*.

The model estimate of the survey biomass of species *s* in Unit *u* is calculated as:

$$B^{surv}_{s,u,y} = \sum_{a=1}^{m} \tilde{w}^{mid}_{s,y,a} S^{surv}_{s,u,a} N_{s,y,a} e^{-Z_{s,y,a}\frac{m^{surv}_u}{12}} \qquad \text{(B11)}$$

where

$S^{surv}_{s,u,a}$ is the survey selectivity for species *s* and age *a* in Unit *u*,

m^{surv}_u is the month in which survey takes place in Unit *u* ($m^{surv}_u = 8$), and

B.1.4. Initial conditions

For the first year (y_0) considered in the model therefore, the stock is assumed to be at a fraction (θ_s) of its pre-exploitation biomass, i.e.:

$$B^{sp}_{s,y_0} = \theta_s \cdot K^{sp}_s \qquad \text{(B12)}$$

with the starting age structure:

$$N_{s,y_0,a} = R_{start,s} N_{start,s,a} \qquad \text{for } 0 \le a \le m_s \qquad \text{(B13)}$$

where

$$N_{start,s,0} = 1 \qquad \text{(B14)}$$

$$N_{start,s,a} = N_{start,s,a-1} e^{-M_{s,a-1}} (1-\phi_s S_{s,a-1}) \qquad \text{for } 1 \le a \le m_s - 1 \qquad \text{(B15)}$$

$$N_{start,s,m} = N_{start,s,m-1} e^{-M_{s,m-1}} (1-\phi_s S_{s,m_s-1}) \Big/ (1-e^{-M_{s,m}} (1-\phi_s S_{s,m})) \qquad \text{(B16)}$$

where ϕ_s characterises the average fishing proportion over the years immediately preceding y_0.

Unless indicated otherwise though, the stock is assumed to be at pristine equilibrium in 1960, i.e. θ =1 and ϕ_s =0 for the results reported here.

B.2. The (penalised) likelihood function

The model is fit to survey abundance indices, and commercial and survey catch-at-length data to estimate model parameters (which may include residuals about the stock-recruitment function, the fishing selectivities, the annual catches or natural mortality, facilitated through the incorporation of penalty functions described below). Contributions by each of these to the negative of the (penalised) log-likelihood (- $\ell n L$) are as follows.

B.2.1. Survey abundance data

The likelihood is calculated assuming that the observed survey index is log-normally distributed about its expected value:

$$I_{s,u,y} = \hat{I}_{s,u,y} \exp\left(\varepsilon^{u}_{s,y}\right) \quad \text{or} \quad \varepsilon_{s,u,y} = \ell n\left(I_{s,u,y}\right) - \ell n\left(\hat{I}_{s,u,y}\right) \tag{B17}$$

where

$I_{s,u,y}$ is the survey biomass index for year *y* , species *s* and Unit *u*,

$\hat{I}_{s,u,y} = \hat{q}_{s,u} \hat{B}^{surv}_{s,u,y}$ is the corresponding model estimate, where $\widehat{B}^{surv}_{s,u,y}$ is the model estimate of survey biomass, given by equation (B10),

$\hat{q}_{s,u}$ is the constant of proportionality (catchability) for species *s* in Unit *u*, and

$\varepsilon_{s,u,y}$ from $N\left(0,\left(\sigma_{s,u,y}\right)^2\right)$.

The contribution of the survey biomass data to the negative of the log-likelihood function (after removal of constants) is then given by:

$$-\ell n\, L^{surv} = \sum_{s}\sum_{u}\sum_{y}\left[\ell n\left(\sigma_{s,u,y}\right) + \left(\varepsilon_{s,u,y}\right)^2 / 2\left(\sigma_{s,u,y}\right)^2\right] \tag{B18}$$

where

$\sigma_{s,u,y}$ is the standard deviation of the residuals for the logarithm of survey index for species *s* in Unit *u* and year *y*.

The catchability coefficient $q_{s,u}$ for survey index for species *s* in Unit *u* is estimated by its maximum likelihood value:

$$\ell n\, \hat{q}_{s,u} = 1/n \sum_{y}\left(\ln I_{s,u,y} - \ln \hat{B}^{surv}_{s,u,y}\right) \tag{B19}$$

A penalty on the survey catchability coefficients is used for all scenarios in the spirit of a prior to avoid the results going into implausible regions of parameter space (particularly *S. fasciatus'* survey catchability *q* going unrealistically high). The following penalty is added to the negative log-likelihood to effect this:

$$-\ell n L^{qpen} = \sum_{i=1}^{n_{survey}}\left[\frac{2\left(q^i - l_b\right)}{\left(u_b - l_b\right)} - 1\right]^p \tag{B20}$$

B.2.2. Commercial catches-at-length

Commercial catches-at-length are not disaggregated by species. The model is therefore fit to the catches-at-length as determined for both species combined. The contribution of the catch-at-length data to the negative of the log-likelihood function under the assumption of an “adjusted” (or "Punt-Kennedy (1997)") lognormal error distribution is given by:

$$-\ell\mathrm{n}\, L^{CAL} = W_{CAL}\sum_{u}\sum_{y}\sum_{l}\left[\ell n\left(\sigma_u^{com} / \sqrt{p_{u,y,l}}\right) + p_{u,y,l}\left(\ell n\, p_{u,y,l} - \ell n\, \hat{p}_{u,y,l}\right)^2 / 2\left(\sigma_u^{com}\right)^2\right] \quad \text{(B21)}$$

where

$p_{u,y,l}$ is the observed proportion of fish (*S. mentella* and *S. fasciatus* combined) caught in year *y* and Unit *u* that are of length *l*,

$\hat{p}_{u,y,l} = \dfrac{\sum_s \hat{C}_{s,u,y,l}}{\sum_{l'}\sum_s \hat{C}_{s,u,y,l'}}$ is the model-predicted proportion of fish (*S. mentella* and *S. fasciatus* combined) caught in year *y* and Unit *u* that are of length *l*,

where

$$\hat{C}_{s,u,y,l} = N_{s,y,a} A_{s,a,l} S_{s,u,y,l} e^{-Z_{s,y,a}/2} \quad \text{(B22)}$$

and σ_u^{com} is the standard deviation associated with the catch-at-length data for Unit *u*, which is estimated in the fitting procedure by:

$$\hat{\sigma}_u^{com} = \sqrt{\sum_y\sum_l p_{u,y,l}\left(\ell n\, p_{u,y,l} - \ell n\, \hat{p}_{u,y,l}\right)^2 / \sum_y\sum_l 1} \quad \text{(B23)}$$

The log-normal error distribution underlying equation (B21) is chosen on the grounds that (assuming no ageing error) variability is likely dominated by a combination of interannual variation in the distribution of fishing effort, and fluctuations (partly as a consequence of such variations) in selectivity-at-age, which suggests that the assumption of a constant coefficient of variation is appropriate. However, for ages poorly represented in the sample, sampling variability considerations must at some stage start to dominate the variance. To take this into account in a simple manner, motivated by binomial distribution properties, the observed proportions are used for weighting so that undue importance is not attached to data based upon a few samples only.

The W_{CAL} weighting factor is set to 0.01 (if not otherwise indicated) to downweight the contribution of the catch-at-length data (which tend to be positively correlated between adjacent length groups) to the overall negative log-likelihood compared to that of the survey biomass data.

Commercial catches-at-length are incorporated in the likelihood function using equation (B20), for which the summation over age *l* is taken from length l_{minus} (considered as a minus group) to l_{plus} (a plus group), see Table B1.

B.2.3. Survey catches-at-length

The survey catches-at-length are incorporated into the negative of the log-likelihood in an analogous manner to the commercial catches-at-length, assuming an adjusted log-normal error distribution (equation (B20)). In this case however, data that are disaggregated by species are available.

$p_{s,u,y,l}^{surv}$ is the observed proportion of fish of species *s* and length *l* in year *y* for survey carried out in Unit *u*,

$\hat{p}^{surv}_{s,u,y,l}$ is the expected proportion of fish of species *s* and length *l* in year *y* in the survey carried out in Unit *u*, given by:

$\hat{p}^{surv}_{s,u,y,l} = \hat{C}^{surv}_{s,u,y,l} / \sum_{l'} \hat{C}^{surv}_{s,u,y,l'}$ is the model-predicted proportion of fish for species *s* caught in year *y* and survey carried out in Unit *u* that are of length *l*,

where

$$\hat{C}^{surv}_{s,u,y,l} = N_{s,y,a} \, A_{s,a,l} S^{surv}_{s,u,l} \, e^{-Z_{s,y,a} \frac{m^{surv}_u}{12}} \quad \text{(B24)}$$

Survey catches-at-length are incorporated in the likelihood function using equation (B21), for which the summation over age *l* is taken from length l_{minus} (considered as a minus group) to l_{plus} (a plus group), see Table B1.

B.2.4. Stock-recruitment function residuals

The stock-recruitment residuals are assumed to be log-normally distributed. Thus, the contribution of the recruitment residuals to the negative of the (now penalised) log-likelihood function is given by:

$$-\ell n L^{SRpen} = \sum_s \sum_{y=y1}^{y2} \left[\varsigma^2_{s,y} / 2\sigma^2_R \right] \quad \text{(B25)}$$

where

$\varsigma_{s,y}$ from $N\left(0, (\sigma_R)^2\right)$, which is estimated for year *y*1 to *y*2 (see equation (B4)), and

σ_R is the standard deviation of the log-residuals, which is input ($\sigma_R = 0.4$ or $\sigma_R = 1.5$)

B.2.5. *Catches*

$$-\ell n L^{\text{Catch}} = \sum_u \sum_y \left[\frac{\ell n C_{u,y} - \ell n \hat{C}_{u,y}}{2\sigma^2_{\text{C}}} \right] \quad \text{(B26)}$$

where

$C_{u,y}$ is the observed catch of both species in year *y* and Unit *u*,

$\hat{C}_{u,y} = \sum_s \hat{C}_{s,u,y}$ is the predicted catch in year *y*, and

σ_{C} is the input CV (=0.2).

No assumption about the species split of the catches is made on input; rather flexibility is allowed in the model by estimating the annual *S. fasciatus* proportion in the catches directly, by means of the following penalty added to the negative log-likelihood:

where

$$-\ell n L^{FPpen} = \sum_u \sum_{y=1960}^{2009} \left[\frac{\left(p^u_y - \mu^u\right)^2}{2\left(\sigma^u\right)^2} \right] \quad \text{(B27)}$$

p^u_y is the estimated proportion of *S. fasciatus* in the catch in year *y* and Unit *u*,

μ^u and σ^u are the mean and standard deviation respectively of the distribution of *S. fasciatus* proportions in Unit *u* based on the survey species split information (McAllister and Duplisea, 2012). For Unit 1, $\mu^u = 0.40$ and $\sigma^u = 0.16$, and for Unit 2, $\mu^u = 0.53$ and $\sigma^u = 0.10$.

B.3. Model parameters

B.4.1. Fishing selectivity-at-length:

The survey fishing selectivity-at-length, $S^{surv}_{s,u,l}$ are estimated directly for a series of lengths (from 10cm to 40cm by 5cm steps) and is taken to be linear between these lengths. The slope from lengths l_{minus} to l_{minus}+1 is assumed to continue exponentially to lower lengths down to length 1. For lengths above l_{plus}, the selectivity is taken to be flat (i.e. $S_l = S_{l_{plus}}$ for $l > l_{plus}$).

The commercial fishing selectivities-at-length, $S_{s,u,l}$ are estimated in terms of a logistic curve given by:

$$S_{s,u,l} = \frac{1}{1+\exp\left(-\left(l-l^c_{s,u}\right)/\delta^c_{s,u}\right)} \qquad \text{(B28)}$$

where

$l^c_{s,u}$ cm is the length-at-50% selectivity for species *s* in Unit <u>*u*</u>,

$\delta^c_{s,u}$ cm^{-1} defines the steepness of the ascending limb of the selectivity curve for species s in Unit *u*.

In practice however, the commercial selectivities have been taken to be the same for the two Units.

Table B1: Minus and plus length groups (in cm) for the commercial and survey CAL.

	S. mentella	*S. fasciatus*
Commercial CAL:		
l_{minus}	20	20
l_{plus}	45	45
Survey CAL:		
l_{minus}	20	20
l_{plus}	45	45

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