Development and diagnostics of the Beaufort Assessment Model applied to tilefish

Sustainable Fisheries Branch, NMFS

SEDAR25-RW06

Date Submitted: 27 September 2011
Revised: 3 October 2011

S E D A R

Southeast Data, Assessment, and Review

==

SEDAR 25−RW−06

Development and diagnostics of the Beaufort assessment model applied to tilefish

Prepared by
Sustainable Fisheries Branch
Southeast Fisheries Science Center
Beaufort, NC

September 2011

SEDAR is a Cooperative Initiative of:
The Caribbean Fishery Management Council
The Gulf of Mexico Fishery Management Council
The South Atlantic Fishery Management Council
NOAA Fisheries Southeast Regional Office
NOAA Fisheries Southeast Fisheries Science Center
The Atlantic States Marine Fisheries Commission
The Gulf States Marine Fisheries Commission

SEDAR Headquarters
The South Atlantic Fishery Management Council
4055 Faber Place #201
North Charleston, SC 29405
(843) 571-4366

1. Introduction

The BAM, a statistical catch-age formulation, was applied to tilefish as the primary stock assessment model. The model is detailed in SEDAR25-RW04, and results are documented in the assessment workshop report. This working paper describes development of the BAM's base run and related diagnostics that were not included elsewhere. Its primary purpose is to provide supplemental information for the RW panel. A brief description developmental and sensitivity model runs is provided in Appendix 1.

2. Model development: weighting of model components

The BAM allows for each component of the likelihood to be weighted by user-supplied values. For data components, these weights were applied by either adjusting CVs (lognormal components) or adjusting effective sample sizes (multinomial components). In this application to tilefish, CVs of landings (in arithmetic space) were assumed equal to 0.05, to achieve a close fit to these time series yet allow some imprecision. In practice, the small CVs are a matter of computational convenience, as they help achieve the desired result of close fits to the landings while avoiding having to solve the Baranov equation iteratively (which is complex when there are multiple fisheries). Thus, weights on landings were not adjusted. Weights on other data components (indices; age and length compositions) were adjusted iteratively, following the methods outlined by Chris Francis in his CIE review of SEDAR 24. These methods were expounded on by Francis (2011) subsequent to the SEDAR25 AW.

2.1. *Model run prior to iterative re-weighting*

Initial weights were those provided by the DW. For indices, the initial CVs were set equal to the values estimated by catch-rate standardization. Effective sample sizes of the multinomial components were assumed equal to the number of trips sampled annually, rather than the number of fish measured, reflecting the belief that the basic sampling unit occurs at the level of trip.

Using those initial weights, the BAM was fit to the data. In this model run, the commercial longline and MARMAP indices did not fit well. Signals from indices were likely swamped by the composition data, which is common in statistical catch-age models and is one reason why iterative re-weighting can be useful (Francis 2011). This model run was considered a sensitivity run in the assessment (Sensitivity Run S5 in the AW report).

2.2. Model run with iterative re-weighting

From that initial fit, we computed standard deviation of normalized residuals (SDNRs). Weights (w) were then calculated for multinomial components as w=1/SDNR^2, and approximated for lognormal components as *w*=1/SDNR. For multinomial components, these weights were applied as multipliers on the effective sample size (*wN*), and for lognormal components, as divisors on CV in arithmetic space (CV/*w*). The model was then re-fit using the new weights, and the procedure was continued until SDNRs were near 1.0. The target of SDNRs near 1.0 matches the assumption of standardized residuals, i.e., distributed N(0,1).

For indices, the normalized residual for year *y* was computed as,

$$r_y = \log\left(\frac{U_{obs,y}}{U_{exp,y}}\right)/\sigma_y$$

where $U_{obs,y}$ and $U_{exp,y}$ are observed and expected values, and $\sigma_y = \sqrt{\log(1 + CV_y^2)}$. For composition data, the normalized residual for year *y* was computed as,

$$r_y = (\mu_{obs,y} - \mu_{exp,y})/\, s.e.(\mu_{obs,y})$$

where $\mu_{obs,y}$ is the observed mean length or age, and $\mu_{exp,y}$ is the expected mean length or age, and s.e. is computed as,

$$s.e.(\mu_{obs,y}) = \sqrt{\left[\sum_i (x_i - \mu_{obs,y})^2 P_{obs,iy}\right]/N_y}$$

Here, N_y is the assumed sample size, and $P_{obs,iy}$ is the observed proportion of fish in the *i*th length or age bin in year *y* with associated length or age x_i. The mean observed value is computed as,

$$\mu_{obs,y} = \sum_i x_i P_{obs,iy}$$

and mean expected values are computed similarly.

Following the above procedure, model components were iteratively re-weighted until SDNRs were near 1.0 (Table 1). Compared to the model without re-weighting, this model with iterative re-weighting showed some improvement in the fits to indices; however these fits still captured little of the observed annual variation and still showed trends in the residual pattern of the commercial longline index (Figure 2). This implied that the composition data may still have been given too much weight, perhaps because the re-weighting procedure did not account for correlations (Francis 2011). This model run was considered a sensitivity run in the assessment (Sensitivity Run S5 in the AW report).

2.3. *Base run: Increased weights on indices of abundance*

For the base run, the AW panel included the component weights described above (Table 1), but increased weights on the commercial longline index to better match the observed annual variation. In many cases, such annual variation may simply be observation error, but the AW panel thought that the index was likely tracking signals of abundance and should be more closely fit.

The AW considered index weights in the range of [1.0, 6.0] for the commercial longline index. This range of weights improved the ability of the model to track annual variation in the index, as revealed by visual inspection of fits and residual patterns (Figure 3). These improvements in fit to the index came with some tradeoff in fits to composition data, particularly age composition data (Figure 3). The AW chose a base-level weight of 3.0 for the index, which appeared to provide a reasonable compromise between fitting the index well and erosion in fitting composition data. Uncertainty analysis included index weighting to examine its influence on results.

3. Alternative Model Configurations

The base run model for tilefish chosen by the assessment workshop panel had some remaining issues with fits to the age composition data. The model solution tended toward a single large year class occurring in 2001 that explained the observed increase in the commercial longline index and an apparent shift in the age structure that occurred in the early 2000's (Figures 4 and 5).

A series of model configurations were applied in an attempt to improve the fit to the age composition data, particularly in the years 2003-2005. These configurations included two periods of separately estimated selectivity patterns in the longline fishery, with different years identifying the break between the periods ranging from 2003-2007. None of these alternate configurations resulted in an improvement in the model fit to the commercial age composition data (Figures 6 - 10). In many cases the fit got worse, despite the additional degrees of freedom (Table 2).

Another alternative configuration allowed for annual varying commercial longline selectivity curves from 1995-2010. Unfortunately, this just allowed the model to use the extra degrees of freedom to over fit the commercial index, at the expense of the age composition data (Table 2, Figures 11 and 12).

An alternative run without the ageing error was explored to determine the influence of this component on the fit to the age composition data. The fits to the commercial longline were not improved (Figure 13).

One of the concerns with the base run configuration was the single large year class. It was thought that the 2006 handline age composition data might be driving this estimate, but a sensitivity run that dropped this data did not change that outcome (Figure 14).

Another model configuration was explored to address the single large year class which dropped the commercial longline age composition data from 2004-2006. This run spread the recruitment pulse out over 3 years but did not improve the fit to the age composition data (Table 2, Figure 15). The AW panel decided that, since there was no evidence to suggest the age data were flawed, this run represents an alternate state but not an improvement over the base run.

In the end, many different configurations were tried, but none of these satisfactorily improved the fit to the age composition data overall (Table 2). Therefore the base run model agreed upon by the assessment workshop panel originally was left unchanged.

4. Model diagnostics

4.1. *Fits to composition data*

Annual fits of the base run to age and length composition data are plotted in the AW report. Residuals of those fits are summarized here using bubble plots, and differences between observations and predictions are quantified by angular deviations (Figure 16). Angular deviation (measured in degrees) is defined as the arc cosine of the dot product of two vectors. A value of 0º indicates perfect agreement between the two vectors (i.e., predicted and observed compositions are identical), and a value of 90º indicates perfect disagreement (the vectors are perpendicular).

4.2. *Standardized proportions at year*

Plots of standardized proportions at year (SPAY) can be useful for examining cohort patterns, as they show when abundance or catches are above or below normal. In terms of abundance, the proportion (*p*) of abundance (*N*) at age *a* in year *y* is computed,

$$p_{a|y} = \frac{N_{ay}}{\sum_a N_{ay}}$$

Such proportions can be computed equally well from predicted or observed catch (*C*) rather than abundance. Whether in terms of *N* or *C*, the mean proportion at age is,

$$\bar{p}_{ay} = \frac{\sum_y p_{a|y}}{Y}$$

where *Y* is the number of years. The standardized proportion at age is then,

$$\acute{p}_{a|y} = \frac{p_{a|y} - \bar{p}_{a|y}}{Y^{-1}\sum_y \left(p_{a|y} - \bar{p}_{a|y}\right)^2}$$

The SPAY plots show how year classes pulse through the population over time (Figure 17). For example, strong year classes of tilefish were predicted in 1994 and 2001 (Figure 17, predicted abundance panel and predicted catch panels). With a few exceptions, the observed catches do not indicate strong cohort patterns. This lack of signal in year-class strength from observed catch at age provided a conflicting pattern with the variability observed in the indices of abundance, and this conflict was perhaps the driving tradeoff between fitting composition data and indices.

4.3. *Likelihood profiles*

Likelihood profiles were computed for several key parameters including steepness, R0, and natural mortality (Tables 3-5, Figure 18). The jagged nature of the profile values suggest some instability in the model. This was investigated during the assessment workshop and it was determined that this was caused by uncertainty in the early 2000s recruitment estimates described in the assessment workshop report. The profile on steepness indicates the overall model tendency toward a high steepness value at the upper bound. Not surprisingly, this is driven primarily by the stock-recruit data. The profile on R0 indicates the minimum estimate is fairly well defined, but driven primarily by stock-recruit estimates. The profile on natural mortality was pointing to a higher value of M, driven primarily by the stock-recruit estimates.

4.4. *Uncertainty analysis: Monte Carlo/Bootstrap*

Uncertainty in the base run was quantified using the mixed Monte Carlo and bootstrap (MCB) approach (Legault et al. 2001), as described in the assessment report. The approach re-fits the assessment model many times to modified data sets (the bootstrap feature) and with variation in several key but not estimated parameters (the Monte Carlo feature). Then, results from the many model fits are compiled to describe uncertainty in the base run estimates.

Parameters subjected to Monte Carlo sampling were drawn from parametric distributions described in the assessment report. The bootstrap procedure on landings, indices, age compositions, and length compositions is described in the assessment report.

The MCB procedure re-fit more than n=3000 trials that differed from the original inputs. This number of trials was sufficient for convergence of standard errors in estimated management quantities (Figure 19).

4. Literature cited

Francis, RICC. 2011. Data weighting in statistical fisheries stock assessment models. Canadian Journal of Fisheries and Aquatic Sciences 68:1124−1138.

Legault, CM, JE Powers, and VR Restrepo. 2001. Mixed Monte Carlo/bootstrap approach to assessing king and Spanish mackerel in the Atlantic and Gulf of Mexico: Its evolution and impact. American Fisheries Society Symposium 24:1−8.

Quinn, TJ II and RB Deriso. 1999. Quantitative Fish Dynamics. Oxford University Press.

Table 1. SDNRs and weights computed in model fits. The component weights from the final iteration are shaded.

		MARMAP	Commercial		MARMAP	Commercial		MARMAP	Commercial	
Run	**Source**		**longline**	**handline**		**longline**	**handline**		**longline**	**handline**
1	CPUE	0.21	2.98		4.77	0.34		4.77	0.34	
	Length comp		2.17	0.76		0.21	1.75		0.21	1.75
	Age comp	5.98	4.78	0.72	0.03	0.04	1.95	0.03	0.04	1.95
2	CPUE	0.63	1.25		1.60	0.80		7.63	0.27	
	Length comp		1.12	1.00		0.80	1.00		0.17	1.75
	Age comp	0.87	1.02	0.98	1.33	0.97	1.03	0.04	0.04	2.01
3	CPUE	0.92	1.64		1.09	0.61		8.33	0.16	
	Length comp		1.20	1.02		0.69	0.97		0.12	1.69
	Age comp	0.84	1.06	1.06	1.43	0.88	0.89	0.05	0.04	1.78
4	CPUE	0.96	1.37		1.04	0.73		8.64	0.12	
	Length comp		1.03	1.02		0.94	0.96		0.11	1.63
	Age comp	0.91	0.97	1.04	1.20	1.06	0.93	0.06	0.04	1.65
5	CPUE	0.99	1.13		1.01	0.89		8.72	0.11	
	Length comp		0.99	1.01		1.01	0.98		0.11	1.60
	Age comp	0.97	0.98	1.05	1.07	1.05	0.91	0.07	0.04	1.50
6	CPUE	1.00	1.04		1.00	0.96				
	Length comp		1.00	1.01		1.01	0.99			
	Age comp	0.99	0.99	1.03	1.01	1.01	0.95			

Table 2. Likelihood values for various run explorations. lk indicates negative log-likelihood, U indicates indices, lenc indicates length compositions, and agec indicates age compositions (cl=commercial longline, ch=commercial handline, ra=recreational, and mm=MARMAP longline).

Sensitivity	lk.total	lk.unwgt.data	lk.U.cl	lk.U.mm	lk.L.cl	lk.L.ch	lk.L.ra	lk.lenc.cl	lk.lenc.ch	lk.agec.cl	lk.agec.ch	lk.agec.mm	lk.priors	lk.SRfit
Base Run	92.8	106.4	24.4	25.1	0.17	0.007	0.008	5.34	21.6	6.10	19.3	4.39	-3.66	-10.0
M low bound	153.1	129.3	22.0	28.1	0.11	0.004	0.005	6.92	26.8	9.74	26.1	9.52	-3.05	26.8
M upper bound	70.9	89.5	21.0	13.8	0.06	0.003	0.005	3.08	21.9	7.85	19.2	2.53	-2.64	-15.9
Steep = 0.94	84.7	113.2	18.6	27.8	0.32	0.012	0.029	7.60	21.9	8.59	21.1	7.15	-2.92	-25.5
Steep = 0.74	99.7	104.4	19.2	25.1	0.11	0.005	0.006	5.99	21.6	6.32	21.3	4.69	-3.76	-0.9
Unwgt Likelihoods	203.2	217.9	17.8	0.8	0.80	0.034	0.063	36.40	13.3	91.47	11.9	45.31	-3.04	-11.6
2% Catchability	91.1	106.8	24.6	24.0	0.18	0.008	0.009	5.55	21.7	6.33	20.0	4.34	-3.65	-12.1
No MARMAP Index	59.4	74.9	15.8	0.0	0.17	0.004	0.019	5.65	21.7	6.44	20.7	4.43	-3.20	-12.3
No Longline Index	29.9	86.3	-	24.3	0.15	0.006	0.007	5.58	21.7	6.59	23.2	4.72	-2.77	-53.6
Selectivity split - 2003	85.6	110.8	25.6	23.1	0.41	0.015	0.042	5.61	21.7	10.04	20.8	3.46	-1.43	-23.8
Selectivity split - 2004	87.8	117.7	29.0	24.9	0.47	0.017	0.040	6.05	21.7	11.34	20.7	3.47	-1.02	-28.9
Selectivity split - 2005	87.4	107.4	18.2	23.5	0.24	0.010	0.016	8.03	21.9	10.16	19.9	5.40	-3.33	-16.7
Selectivity split - 2006	85.1	117.6	21.6	28.0	0.39	0.015	0.042	8.45	21.8	11.61	20.4	5.38	-2.43	-30.1
Selectivity split - 2007	90.4	106.3	24.4	24.5	0.17	0.007	0.008	5.14	21.5	6.62	19.5	4.39	-3.44	-12.5
Time-varying L50 (1995-2010)	65.6	101.4	3.7	26.9	0.67	0.026	0.072	9.22	21.8	12.13	21.5	5.42	-3.23	-42.1
Random walk in U.cl q	42.9	89.2	3.4	24.0	0.16	0.007	0.012	5.60	21.7	6.55	23.2	4.59	-2.78	-52.9
Drop 2004-06 cl age comps	91.6	102.7	18.4	26.5	0.18	0.008	0.009	5.73	21.67	4.99	20.3	4.89	-3.57	-7.51

Table 3. Likelihood profile over steepness (h). lk indicates negative log-likelihood, U indicates indices, lenc indicates length compositions, and agec indicates age compositions (cl=commercial longline, ch=commercial handline, ra=recreational, and mm=MARMAP longline).

h	lk.total	lk.unwgt.data	lk.U.cl	lk.U.mm	lk.L.cl	lk.L.ch	lk.L.ra	lk.lenc.cl	lk.lenc.ch	lk.agec.cl	lk.agec.ch	lk.agec.mm	lk.priors	lk.SRfit
0.225	145.4	123.8	24.16	14.74	0.00	0.00	0.00	4.05	22.39	16.95	33.13	8.35	-1.65	23.31
0.25	134.4	116.6	23.57	17.76	0.01	0.00	0.00	4.33	21.63	13.27	29.67	6.37	-1.86	19.62
0.275	131.9	115.9	23.50	18.06	0.01	0.00	0.00	4.29	21.66	13.05	29.05	6.31	-2.09	18.09
0.3	136.9	117.9	25.06	17.62	0.01	0.00	0.00	3.30	21.28	14.74	28.66	7.26	-2.10	21.05
0.325	134.9	117.3	25.06	17.85	0.01	0.00	0.00	3.23	21.29	14.49	28.15	7.21	-2.28	19.87
0.35	125.1	112.8	24.80	19.82	0.03	0.00	0.00	5.85	21.99	9.92	24.66	5.72	-1.97	14.31
0.375	131.2	116.1	25.07	18.27	0.01	0.00	0.00	3.10	21.31	14.04	27.21	7.10	-2.61	17.66
0.4	129.4	115.6	25.07	18.46	0.02	0.00	0.00	3.04	21.32	13.83	26.78	7.06	-2.75	16.61
0.425	119.8	111.1	23.17	19.53	0.02	0.00	0.00	3.98	21.62	11.25	25.74	5.82	-2.95	11.62
0.45	126.2	114.7	25.09	18.86	0.02	0.00	0.00	2.94	21.36	13.44	25.96	6.98	-3.01	14.56
0.475	116.4	109.9	23.17	19.91	0.03	0.00	0.00	3.89	21.60	10.79	24.80	5.69	-3.14	9.63
0.5	114.8	109.3	23.18	20.09	0.03	0.00	0.00	3.85	21.59	10.57	24.37	5.63	-3.22	8.65
0.525	112.1	109.0	24.56	21.44	0.05	0.00	0.00	5.58	21.76	8.45	22.06	5.05	-2.83	5.97
0.55	111.6	108.3	23.22	20.45	0.04	0.00	0.00	3.78	21.57	10.13	23.58	5.52	-3.37	6.71
0.575	110.1	107.8	23.25	20.63	0.04	0.00	0.00	3.75	21.56	9.91	23.21	5.46	-3.43	5.73
0.6	107.3	107.9	24.48	22.18	0.07	0.00	0.00	5.51	21.69	7.88	21.26	4.79	-3.09	2.54
0.625	107.2	107.0	23.34	21.00	0.05	0.00	0.00	3.71	21.53	9.47	22.52	5.35	-3.55	3.76
0.65	105.2	100.7	18.35	22.96	0.06	0.00	0.00	4.17	21.83	7.24	20.11	5.98	-3.13	7.63
0.675	104.1	105.1	19.75	24.22	0.08	0.00	0.00	5.98	21.61	6.65	22.03	4.77	-3.74	2.78
0.7	102.5	104.8	19.55	24.53	0.09	0.00	0.00	5.98	21.61	6.52	21.76	4.73	-3.76	1.43
0.725	100.8	104.5	19.32	24.88	0.11	0.00	0.01	5.99	21.62	6.39	21.50	4.70	-3.77	0.01
0.75	99.0	100.6	18.90	23.70	0.09	0.00	0.00	3.96	21.74	6.96	19.42	5.87	-3.46	1.85
0.775	97.3	104.0	18.84	25.60	0.13	0.01	0.01	5.96	21.64	6.17	20.97	4.70	-3.72	-3.04
0.8	96.0	100.8	19.29	24.05	0.11	0.00	0.00	3.87	21.70	6.80	19.14	5.83	-3.59	-1.21
0.825	93.7	103.7	18.45	26.31	0.17	0.01	0.01	5.86	21.66	5.98	20.46	4.80	-3.59	-6.46
0.85	91.8	103.7	18.36	26.62	0.19	0.01	0.01	5.78	21.67	5.89	20.25	4.90	-3.51	-8.39
0.875	90.6	106.9	24.36	25.79	0.19	0.01	0.01	5.38	21.60	5.84	19.17	4.57	-3.72	-12.64
0.9	87.9	104.1	18.50	27.11	0.23	0.01	0.01	5.59	21.68	5.77	19.98	5.24	-3.34	-12.84
0.925	86.0	104.7	18.75	27.27	0.25	0.01	0.01	5.48	21.69	5.73	19.94	5.51	-3.25	-15.42
0.95	86.0	104.7	18.75	27.27	0.25	0.01	0.01	5.48	21.69	5.73	19.94	5.51	-3.25	-15.42
0.975	82.1	106.3	19.62	27.32	0.29	0.01	0.02	5.27	21.71	5.73	20.12	6.17	-3.05	-21.15

Table 4. Likelihood profile over R0. lk indicates negative log-likelihood, U indicates indices, lenc indicates length compositions, and agec indicates age compositions (cl=commercial longline, ch=commercial handline, ra=recreational, and mm=MARMAP longline).

R0	lk.total	lk.unwgt.data	lk.U.cl	lk.U.mm	lk.L.cl	lk.L.ch	lk.L.ra	lk.lenc.cl	lk.lenc.ch	lk.agec.cl	lk.agec.ch	lk.agec.mm	lk.priors	lk.SRfit
1.00E+05	151.57	95.79	22.86	16.11	0.05	0.00	0.01	3.72	21.21	9.16	18.60	4.07	7.14	48.64
1.25E+05	160.41	115.66	27.72	20.60	0.14	0.01	0.01	5.64	22.13	10.81	21.31	7.29	5.00	39.75
1.50E+05	141.36	102.40	26.02	11.48	0.08	0.00	0.01	6.00	21.84	9.93	19.47	7.57	2.67	36.30
1.75E+05	122.15	92.30	25.37	13.99	0.06	0.00	0.01	4.04	21.25	7.68	16.14	3.76	1.57	28.28
2.00E+05	140.20	113.76	26.47	21.88	0.26	0.01	0.02	6.66	23.81	12.52	18.10	4.04	1.34	25.09
2.25E+05	110.12	91.44	24.94	13.95	0.07	0.00	0.02	4.28	21.61	7.62	15.94	3.02	-0.31	18.99
2.50E+05	107.78	92.71	24.70	14.26	0.08	0.00	0.01	4.24	21.49	8.20	16.11	3.61	-0.98	16.05
2.75E+05	111.31	97.75	21.95	18.09	0.11	0.00	0.01	6.61	22.54	7.08	18.40	2.94	-2.13	15.70
3.00E+05	101.70	94.59	24.58	16.88	0.13	0.00	0.01	4.62	21.37	6.69	16.71	3.60	-2.63	9.74
3.25E+05	99.74	96.51	24.47	18.72	0.13	0.00	0.01	4.57	21.26	6.44	17.11	3.80	-2.95	6.18
3.50E+05	100.18	98.01	23.01	19.10	0.09	0.00	0.01	2.95	21.22	8.39	18.51	4.73	-3.29	5.46
3.75E+05	97.61	99.85	23.30	20.71	0.09	0.00	0.01	3.16	21.24	7.73	18.74	4.86	-3.64	1.39
4.00E+05	92.97	105.29	24.31	24.85	0.14	0.01	0.01	5.12	21.55	6.02	18.95	4.34	-3.64	-8.69
4.25E+05	93.29	107.82	24.49	24.94	0.25	0.01	0.01	5.65	21.65	6.35	20.10	4.38	-3.68	-10.84
4.50E+05	95.50	103.80	20.32	23.28	0.28	0.01	0.01	4.29	21.84	7.26	21.19	5.33	-3.62	-4.67
4.75E+05	98.62	105.55	20.45	21.80	0.32	0.01	0.01	4.63	22.05	7.83	23.23	5.23	-3.56	-3.37
5.00E+05	102.01	107.46	20.57	20.52	0.30	0.01	0.01	4.95	22.27	8.36	25.20	5.28	-3.53	-1.92
5.25E+05	105.26	113.53	24.90	18.13	0.23	0.01	0.01	5.00	22.22	9.75	28.09	5.19	-3.85	-4.42
5.50E+05	108.00	115.45	25.03	17.29	0.19	0.01	0.00	5.12	22.37	10.36	29.73	5.36	-3.82	-3.63
5.75E+05	110.46	117.19	25.14	16.66	0.16	0.01	0.00	5.24	22.49	10.85	31.13	5.51	-3.80	-2.92
6.00E+05	112.67	118.75	25.25	16.17	0.13	0.00	0.00	5.36	22.60	11.26	32.33	5.65	-3.78	-2.31
6.25E+05	115.41	115.61	20.95	16.81	0.14	0.00	0.00	6.04	23.11	10.21	32.14	6.21	-3.40	3.20
6.50E+05	119.77	125.56	26.22	16.22	0.13	0.00	0.00	8.07	23.47	11.30	34.15	5.99	-3.60	-2.18
6.75E+05	119.11	118.00	21.06	16.08	0.10	0.00	0.00	6.30	23.33	10.71	33.87	6.54	-3.36	4.47
7.00E+05	120.70	119.04	21.11	15.79	0.09	0.00	0.00	6.40	23.42	10.93	34.61	6.68	-3.35	5.01

Table 5. Likelihood profile over natural mortality (M). In each case, age dependent Lorenzen natural mortality was scaled to M, as in the base run. lk indicates negative log-likelihood, U indicates indices, lenc indicates length compositions, and agec indicates age compositions (cl=commercial longline, ch=commercial handline, ra=recreational, and mm=MARMAP longline).

M	M sat	lk.total	lk.unwgt.data	lk.U.cl	lk.U.mm	lk.L.cl	lk.L.ch	lk.L.ra	lk.lenc.cl	lk.lenc.ch	lk.agec.cl	lk.agec.ch	lk.agec.mm	lk.priors	lk.SRfit
0.5	0.05	134.27	116.25	21.63	25.95	0.09	0.00	0.00	3.35	23.10	10.62	23.64	7.86	-2.02	20.04
0.55	0.05	138.85	121.10	25.49	24.06	0.08	0.00	0.00	2.88	22.64	12.88	24.48	8.59	-2.16	19.90
0.6	0.06	134.57	120.60	25.44	24.28	0.09	0.00	0.00	2.90	22.49	12.91	24.16	8.33	-2.16	16.13
0.65	0.06	118.25	115.84	23.10	29.44	0.12	0.01	0.01	5.88	22.97	7.58	19.43	7.30	-1.60	4.01
0.7	0.07	116.98	113.02	22.57	25.62	0.11	0.00	0.00	3.67	22.36	9.86	22.21	6.61	-1.99	5.96
0.75	0.07	112.11	112.04	18.22	29.43	0.14	0.01	0.01	6.55	22.49	6.88	21.03	7.29	-1.93	2.00
0.8	0.08	111.60	120.20	23.83	30.36	0.21	0.01	0.02	8.08	22.97	8.05	20.44	6.25	-1.77	-6.83
0.85	0.08	104.41	108.15	18.47	28.20	0.16	0.01	0.01	6.24	22.03	6.44	21.06	5.54	-1.85	-1.89
0.9	0.09	100.87	106.59	18.41	27.70	0.17	0.01	0.01	6.10	21.88	6.24	20.79	5.28	-1.78	-3.93
0.95	0.09	97.40	107.71	24.28	25.80	0.16	0.01	0.01	5.41	21.68	6.29	19.46	4.62	-1.76	-8.56
1	0.10	94.65	106.63	24.42	25.24	0.17	0.01	0.01	5.36	21.58	6.10	19.34	4.40	-1.81	-10.18
1.05	0.10	92.08	105.66	24.55	24.69	0.18	0.01	0.01	5.33	21.52	5.94	19.24	4.21	-1.85	-11.73
1.1	0.11	89.67	104.82	24.67	24.16	0.18	0.01	0.01	5.32	21.47	5.79	19.17	4.03	-1.90	-13.25
1.15	0.11	87.41	104.16	24.77	23.67	0.19	0.01	0.01	5.35	21.45	5.67	19.15	3.87	-1.96	-14.79
1.2	0.12	85.29	103.79	24.83	23.30	0.20	0.01	0.01	5.43	21.45	5.59	19.21	3.75	-2.03	-16.48
1.25	0.12	83.22	105.25	23.84	23.92	0.24	0.01	0.02	6.01	21.51	5.98	19.74	3.98	-2.19	-19.83
1.3	0.13	81.23	104.63	23.78	23.22	0.25	0.01	0.02	6.04	21.54	6.08	19.91	3.79	-2.18	-21.22
1.35	0.13	79.31	105.62	20.84	23.14	0.28	0.01	0.02	7.10	21.76	7.99	20.80	3.68	-1.79	-24.52
1.4	0.14	76.71	97.17	19.71	20.88	0.19	0.01	0.01	5.01	21.51	5.75	20.06	4.05	-1.47	-18.98
1.45	0.14	75.32	96.76	19.89	20.24	0.18	0.01	0.01	4.95	21.54	5.81	20.15	3.97	-1.47	-19.97
1.5	0.15	74.09	96.41	20.08	19.64	0.18	0.01	0.01	4.89	21.59	5.88	20.25	3.88	-1.47	-20.85
1.55	0.15	73.02	96.12	20.27	19.10	0.17	0.01	0.01	4.85	21.64	5.96	20.36	3.76	-1.47	-21.63
1.6	0.16	72.08	95.87	20.47	18.60	0.16	0.01	0.01	4.81	21.69	6.04	20.46	3.62	-1.48	-22.31
1.65	0.16	71.29	95.66	20.66	18.15	0.14	0.01	0.01	4.78	21.75	6.12	20.57	3.47	-1.49	-22.89
1.7	0.17	70.62	95.48	20.83	17.74	0.13	0.01	0.01	4.75	21.81	6.21	20.67	3.33	-1.49	-23.37
1.75	0.17	70.08	95.32	20.97	17.38	0.12	0.00	0.01	4.73	21.86	6.29	20.77	3.20	-1.49	-23.74
1.8	0.17	69.66	95.16	21.08	17.06	0.10	0.00	0.01	4.71	21.91	6.37	20.85	3.07	-1.49	-24.00
1.85	0.18	69.35	94.95	21.14	16.79	0.09	0.00	0.01	4.69	21.96	6.44	20.92	2.92	-1.48	-24.12
1.9	0.18	69.13	94.67	21.15	16.55	0.08	0.00	0.01	4.68	22.01	6.50	20.96	2.74	-1.46	-24.09
1.95	0.19	68.98	94.28	21.10	16.32	0.07	0.00	0.01	4.67	22.05	6.55	20.99	2.52	-1.41	-23.89
2	0.19	68.88	93.82	21.01	16.08	0.06	0.00	0.01	4.66	22.09	6.60	21.00	2.30	-1.34	-23.60

Figure 1. Estimated spawner-recruit curve, recruitment time series and two indices (cl=commercial longline and mm=MARMAP longline) from model run without iterative re-weighting (tile081 run).

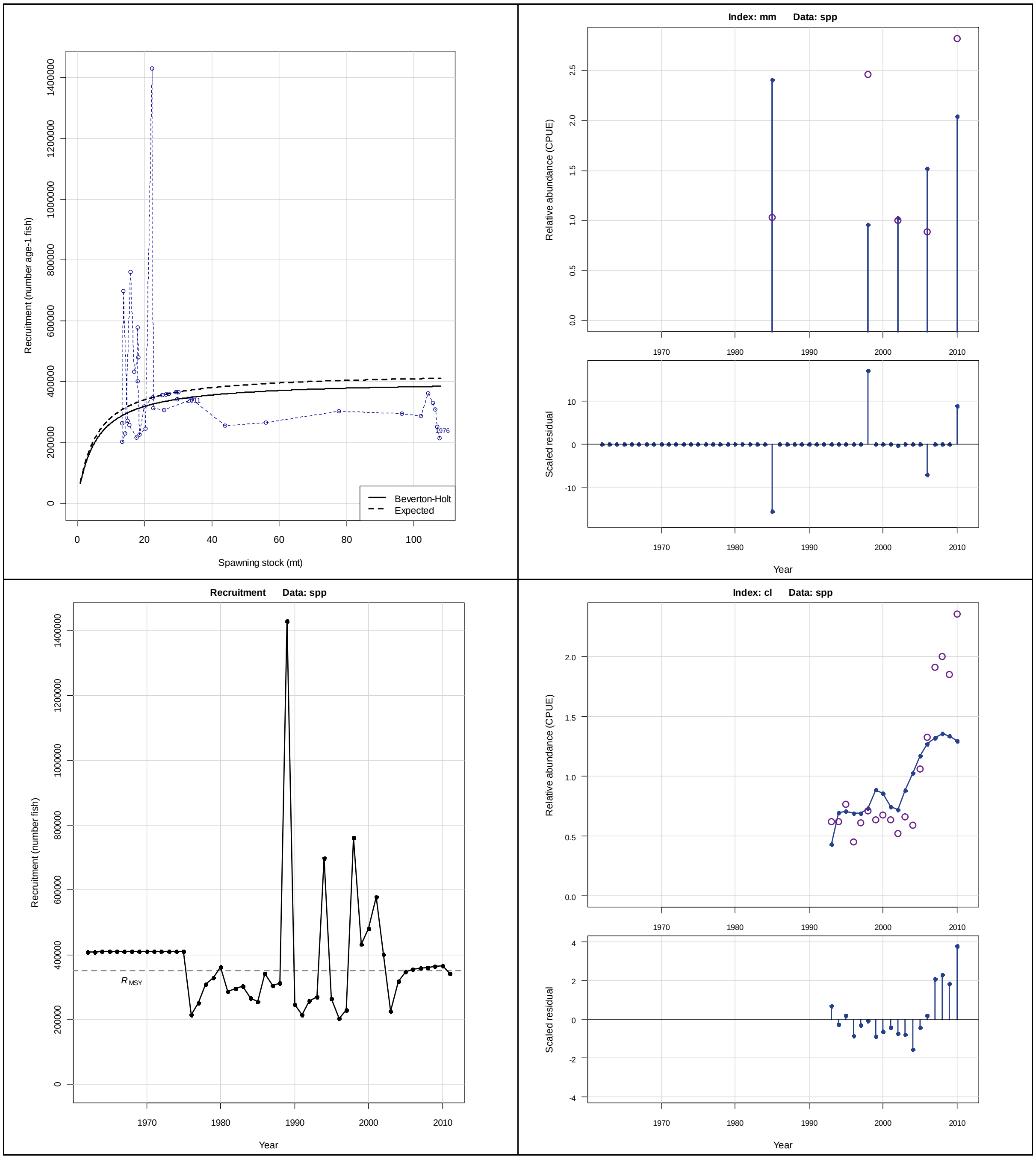


Figure 2. Estimated spawner-recruit curve, recruitment time series and two indices (cl=commercial longline and mm=MARMAP longline) from model run with MARMAP longline index and composition data iteratively re-weighted . The commercial longline index weight was increased to 3 (base run configuration, tile076). Weights shown in Table 1.

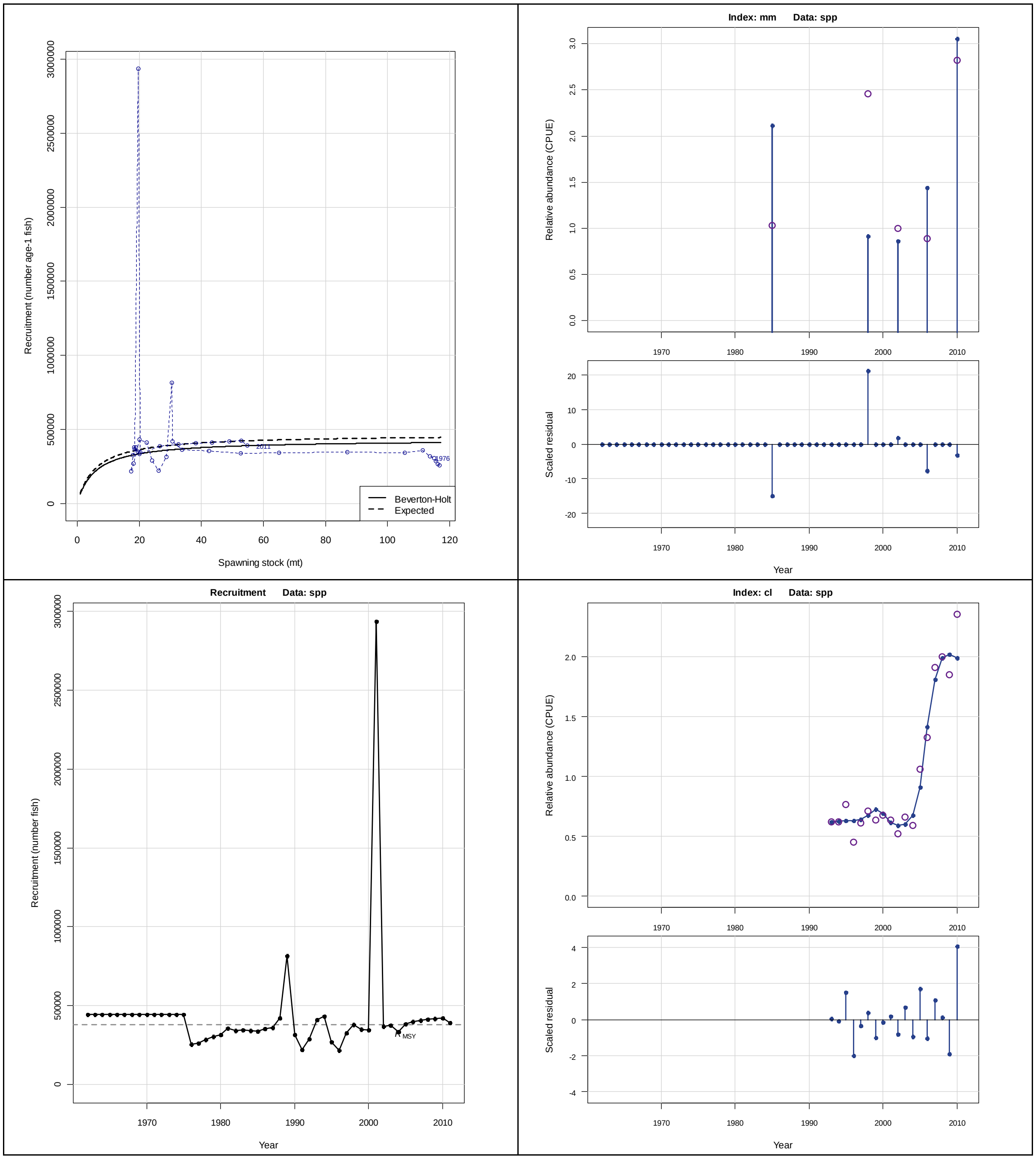
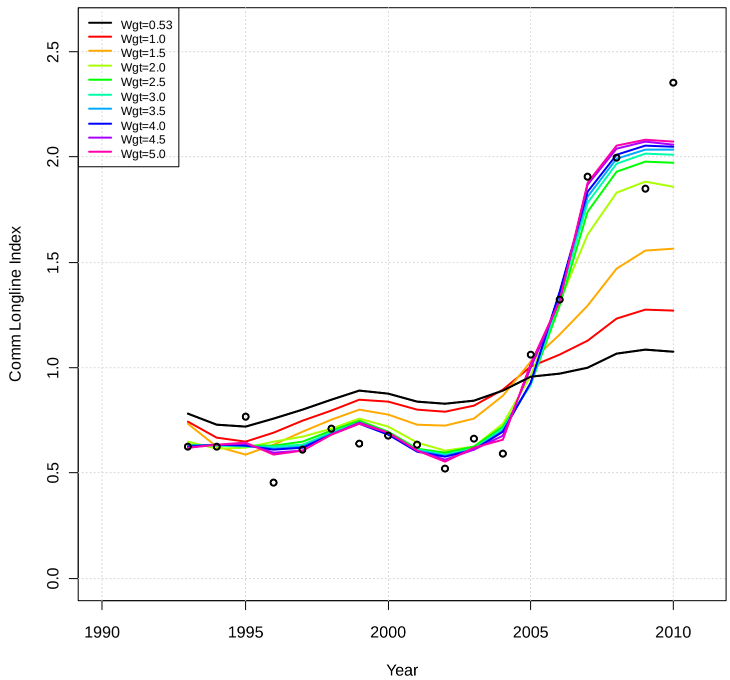


Figure 3. Effect of increased weight on the commercial longline index. Top panel: Fit to the commercial longline index over the range of weights from 1 to 5 on commercial longline. Bottom panel: Predicted recruitment patterns over the same range of commercial longline weights.



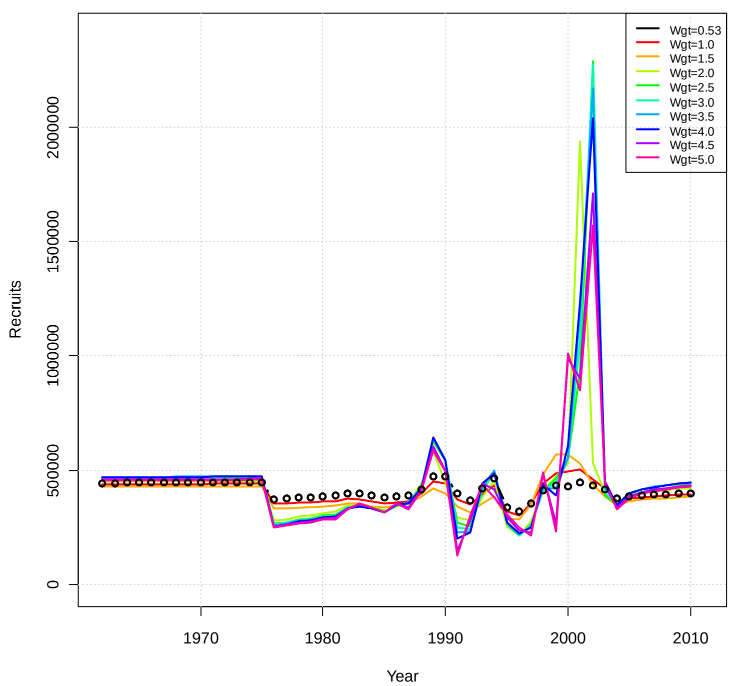


Figure 4. Recruitment time series for the base run. Dashed line indicates expected recruitment at MSY.

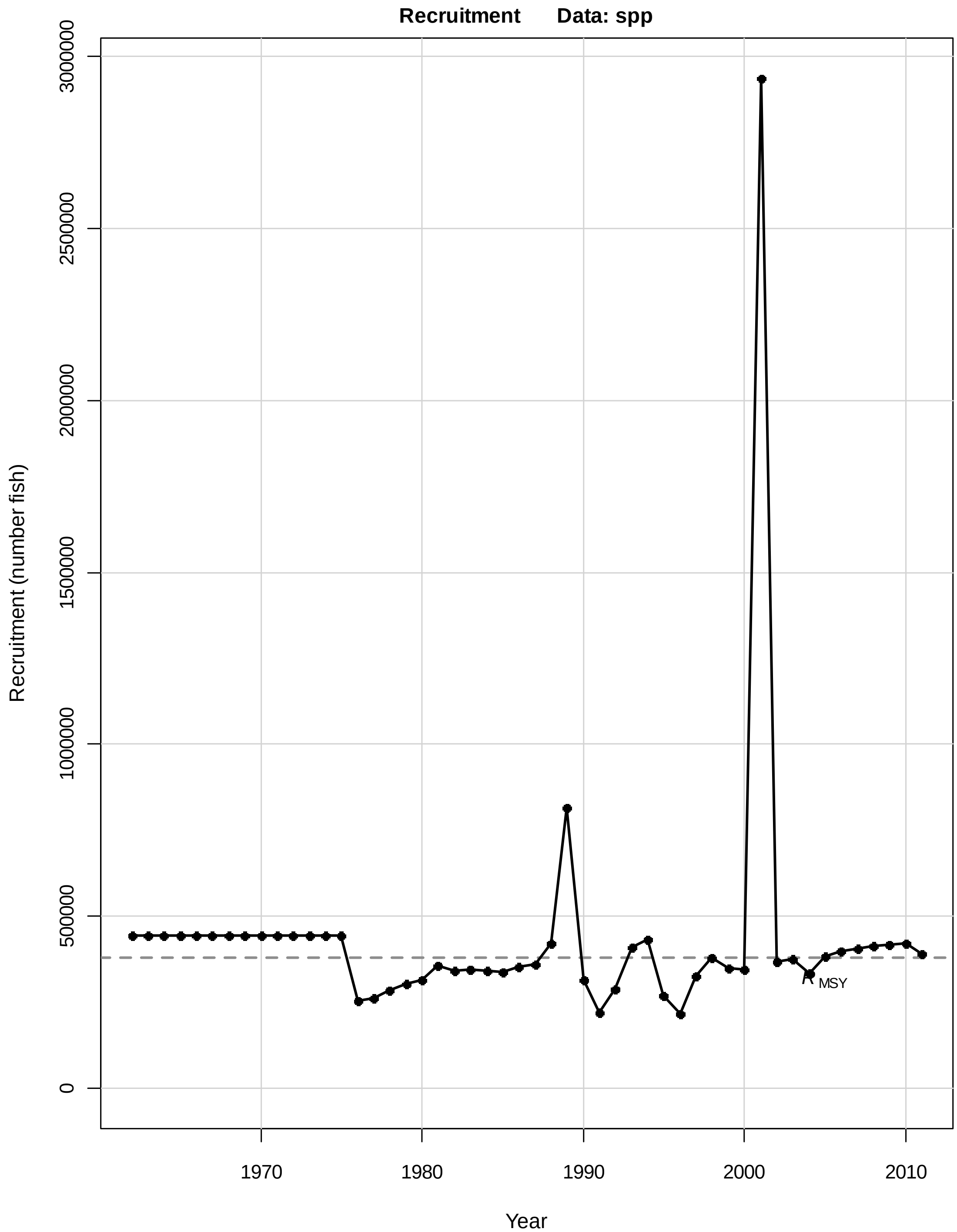


Figure 5. Fit of the base run to the commercial longline age composition for 2003-10.

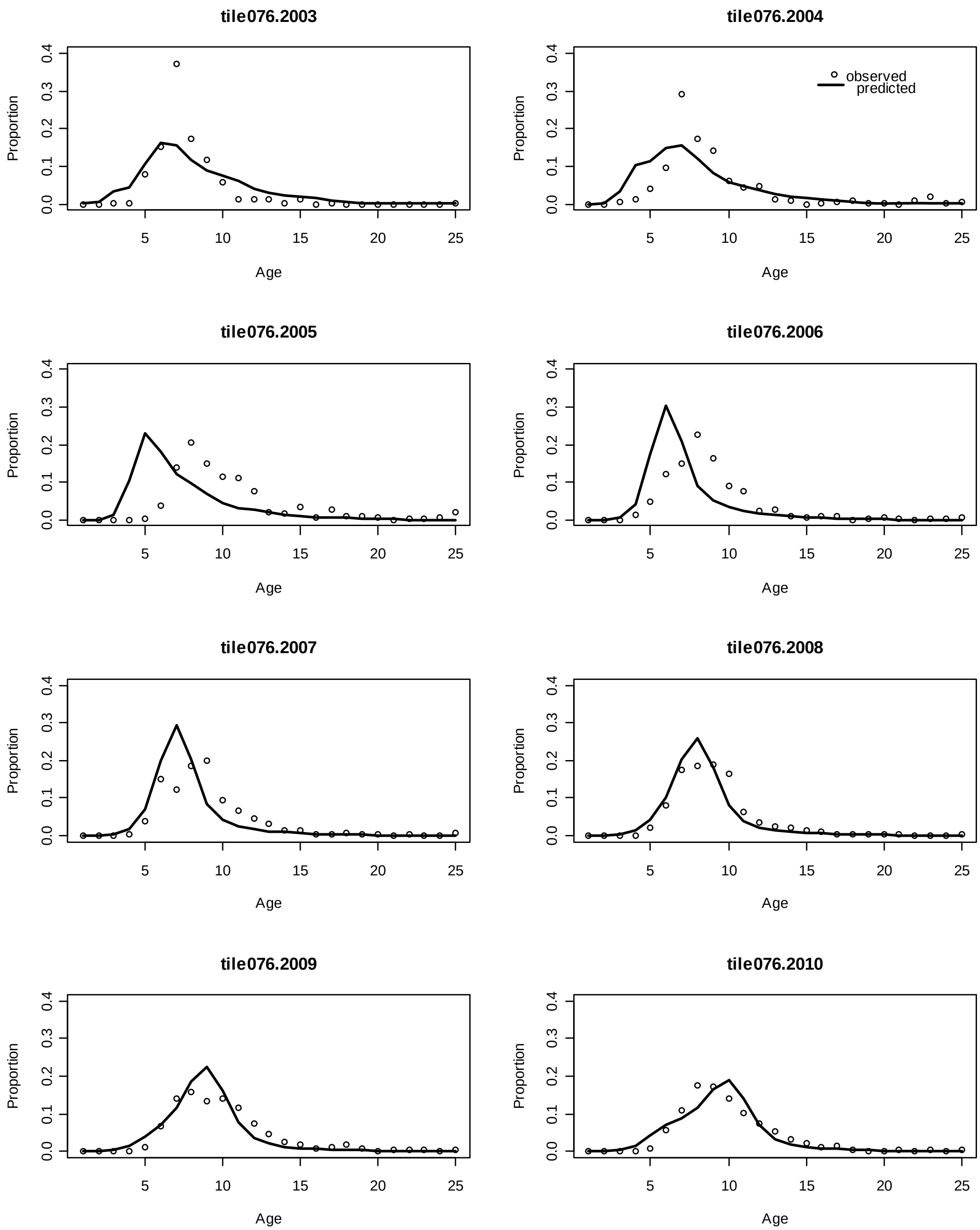


Figure 6. Fit of the base run, modified with two periods of logistic selectivity for commercial longlines starting in 2003 (tile088, s9), to the commercial longline age composition for 2003-10 (A) and deviations of the fit to the age composition (B).

A.

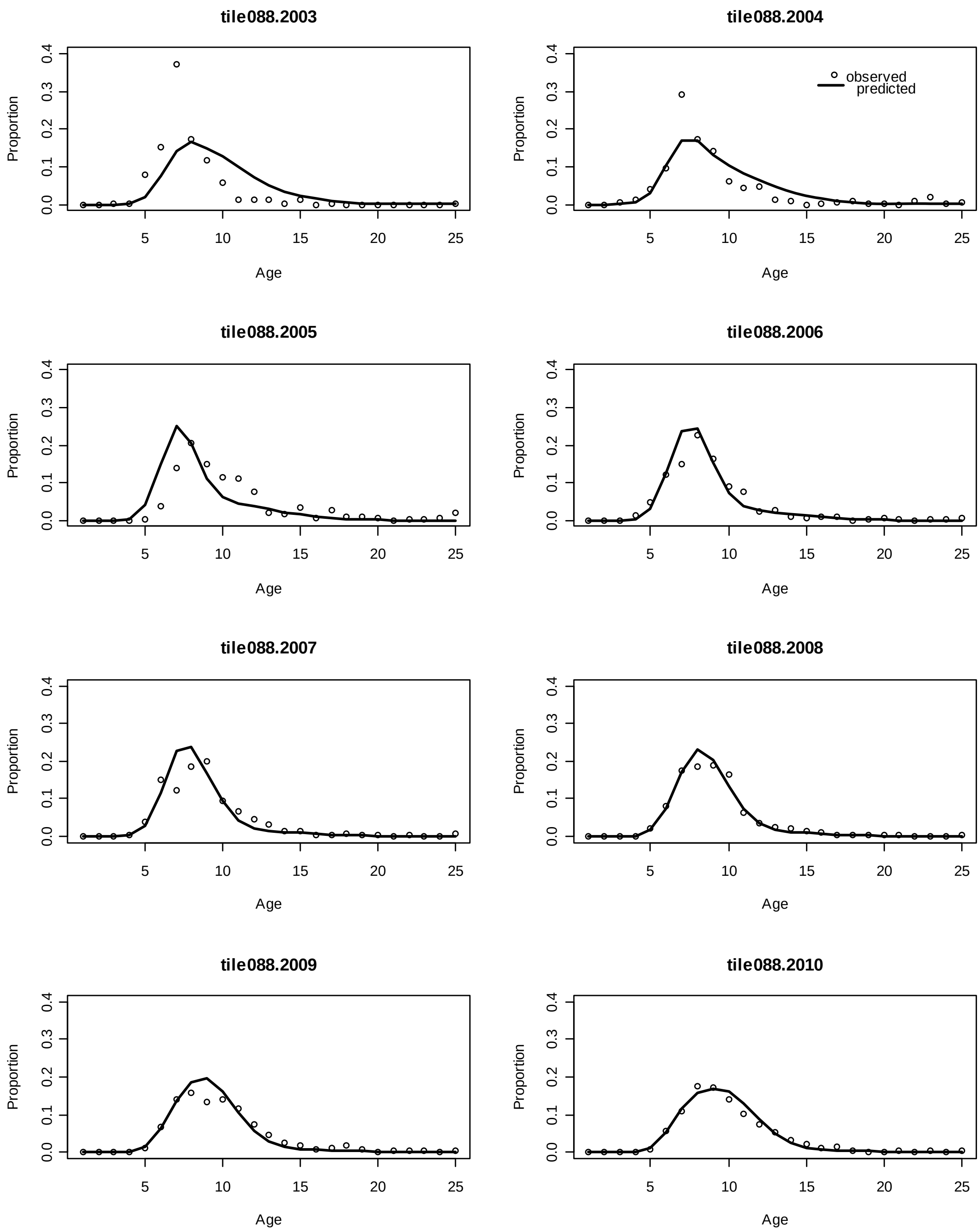


Figure 6 B.

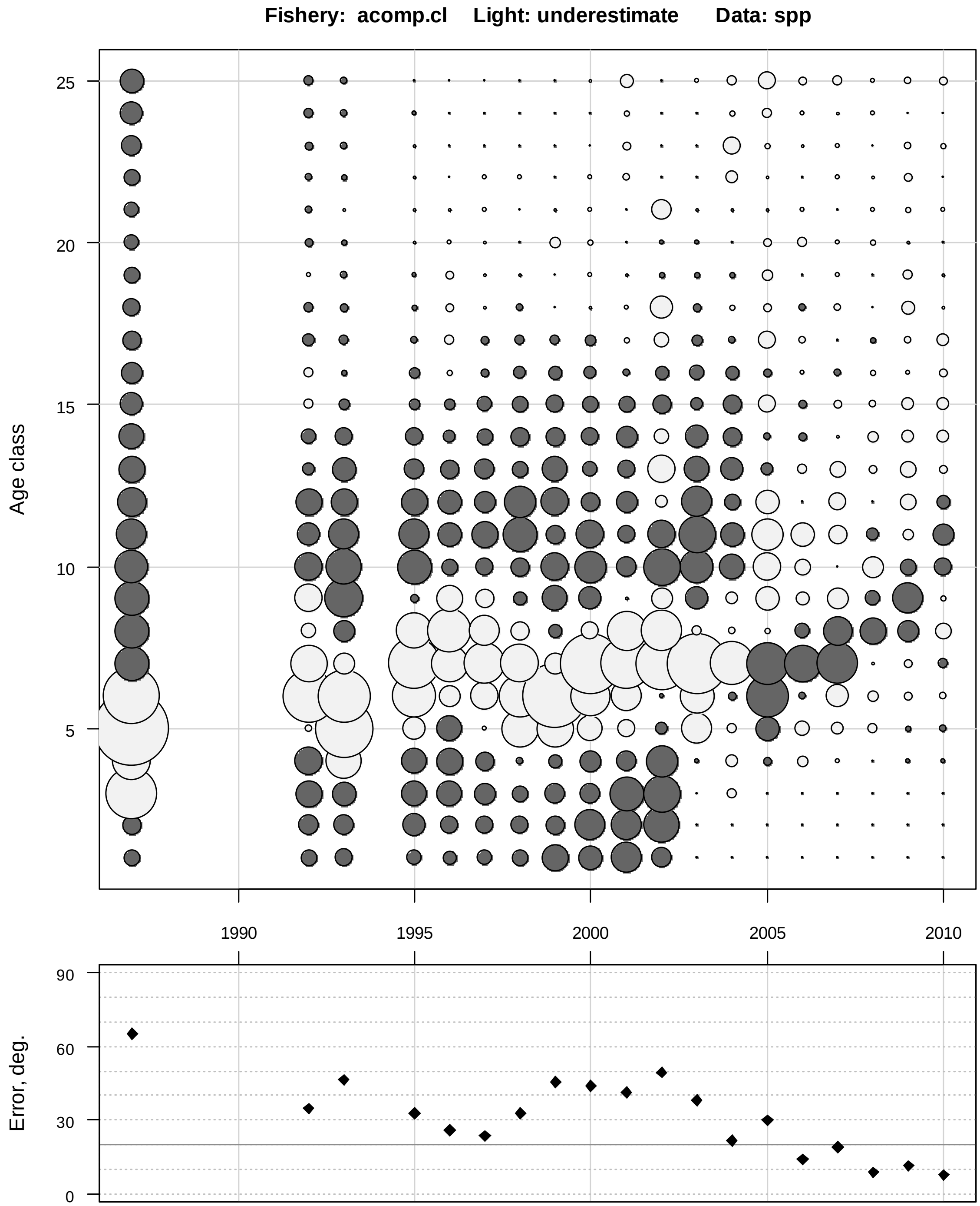

Fishery: acomp.cl Light: underestimate Data: spp
Age class
Error, deg.
25
20
15
10
5
1990
1995
2000
2005
2010
90
60
30
0

Figure 7. Fit of the base run, modified with two periods of logistic selectivity for commercial longlines starting in 2004 (tile089, s10), to the commercial longline age composition for 2003-10 (A) and deviations of the fit to the age composition (B).

A.

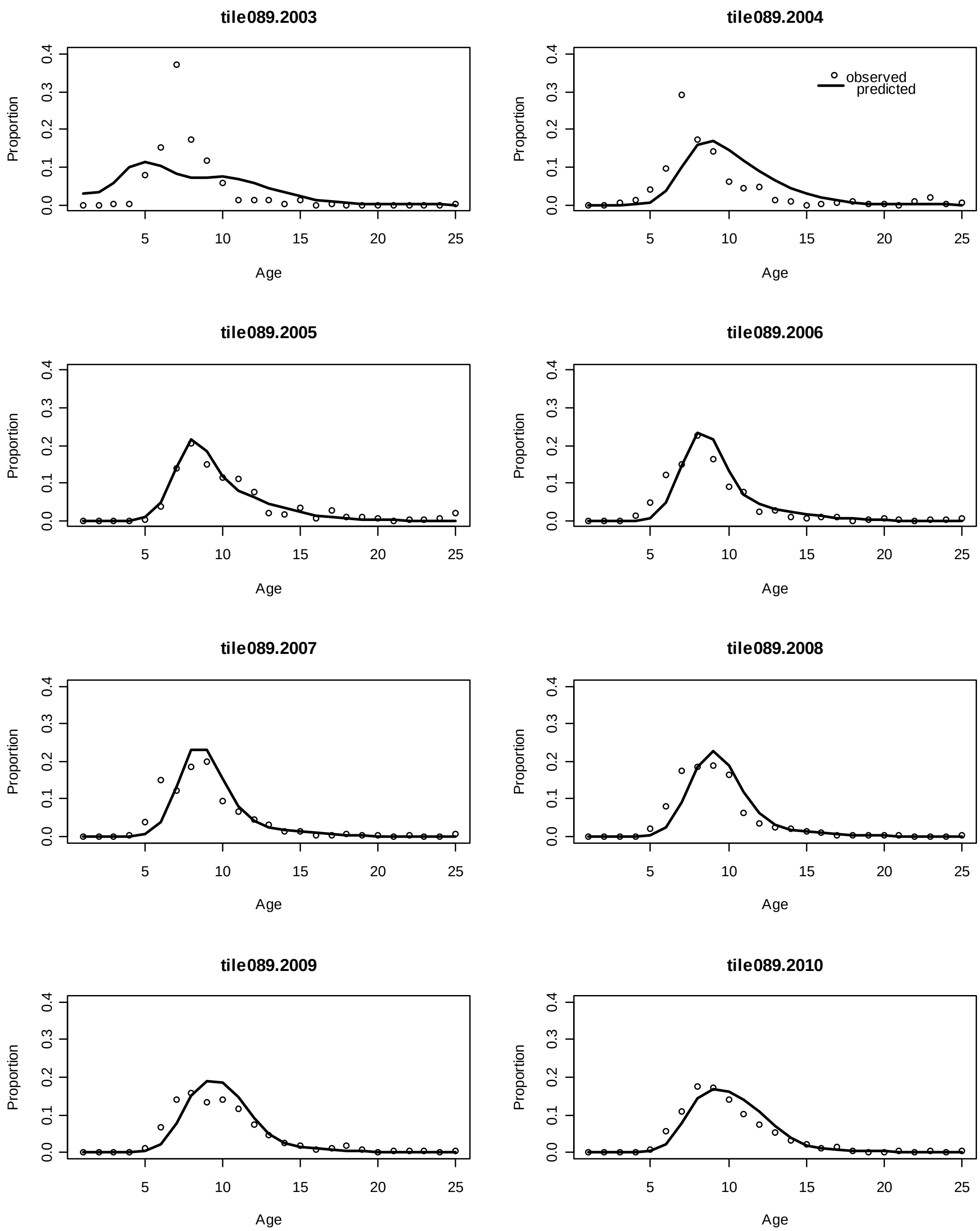


Figure 7 B.

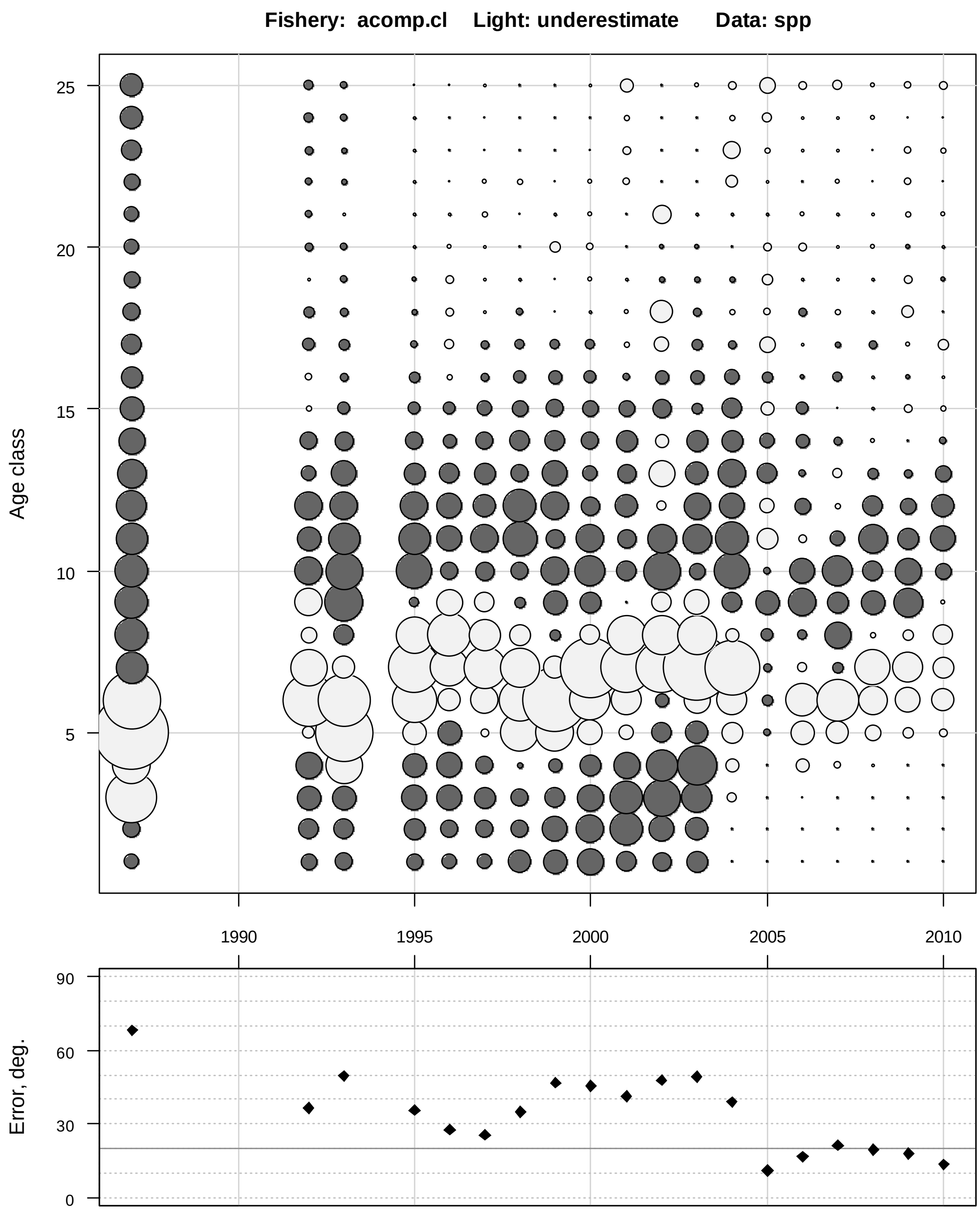

Fishery: acomp.cl Light: underestimate Data: spp
Age class
25
20
15
10
5
1990
1995
2000
2005
2010
Error, deg.
90
60
30
0

Figure 8. Fit of the base run, modified with two periods of logistic selectivity for commercial longlines starting in 2005 (tile085, s11), to the commercial longline age composition for 2003-10 (A) and deviations of the fit to the age composition (B).

A.

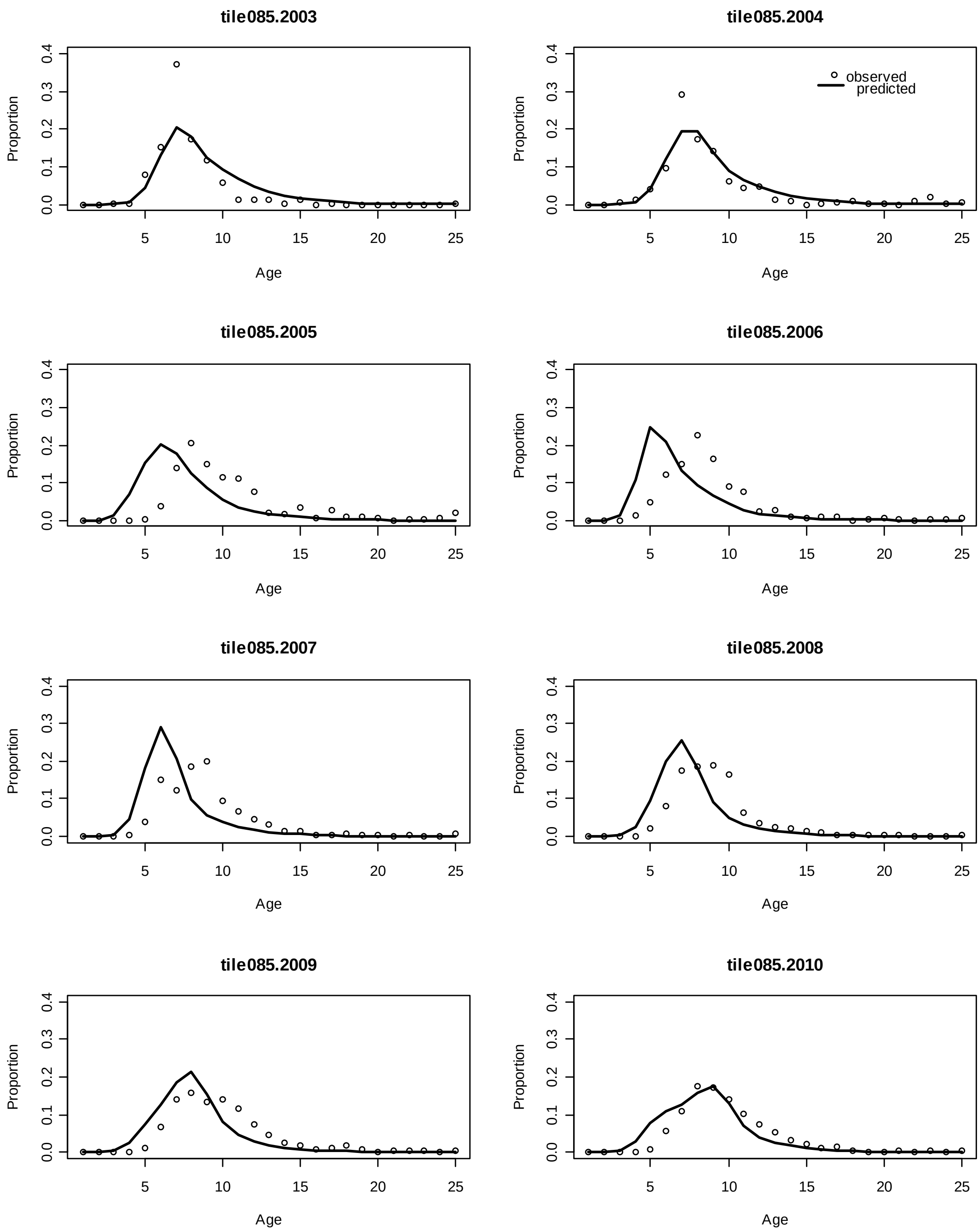


Figure 8 B.

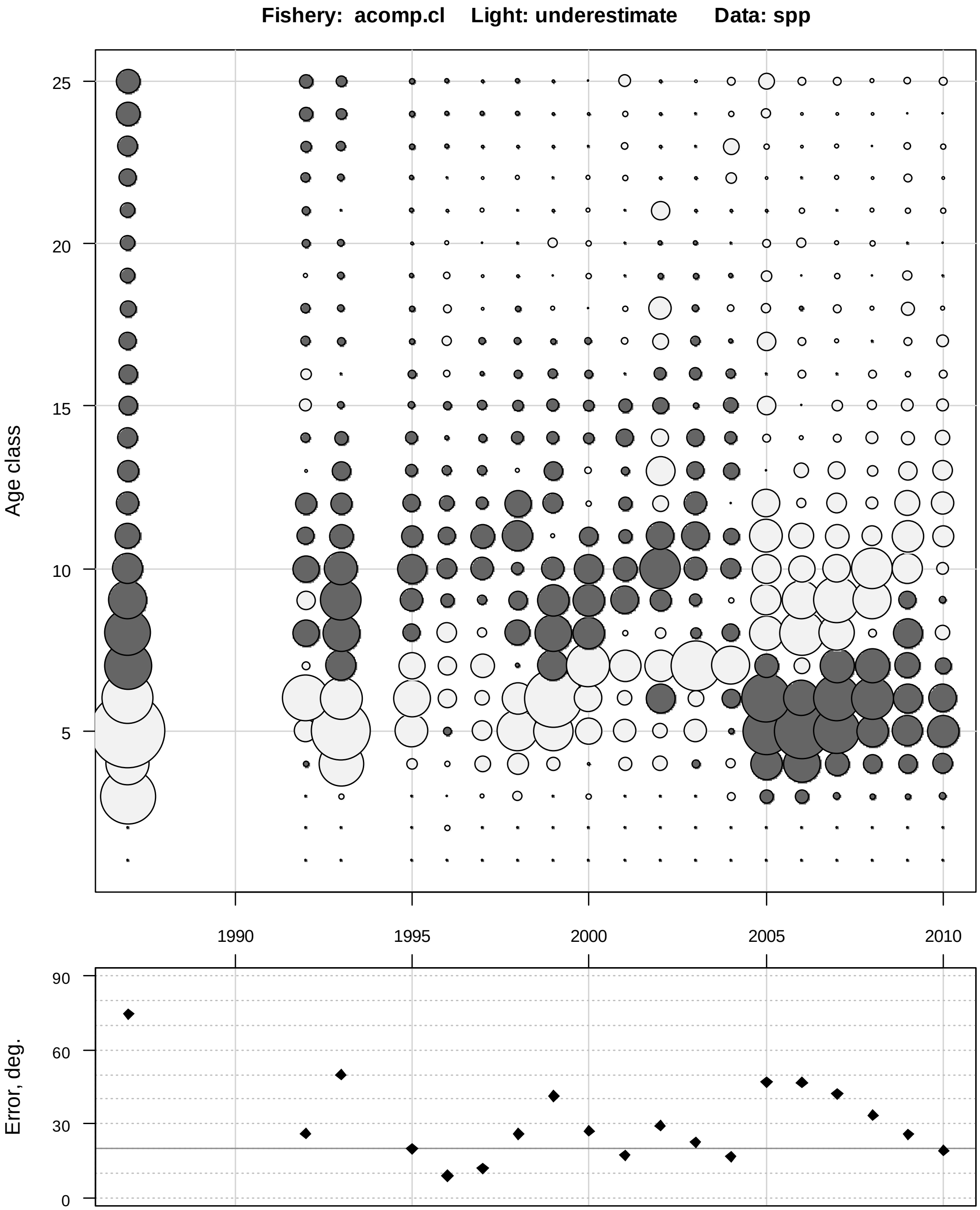

Fishery: acomp.cl Light: underestimate Data: spp
Age class
Error, deg.
1990
1995
2000
2005
2010
5
10
15
20
25
0
30
60
90

Figure 9. Fit of the base run, modified with two periods of logistic selectivity for commercial longlines starting in 2006 (tile090, s12), to the commercial longline age composition for 2003-10 (A) and deviations of the fit to the age composition (B).

A.

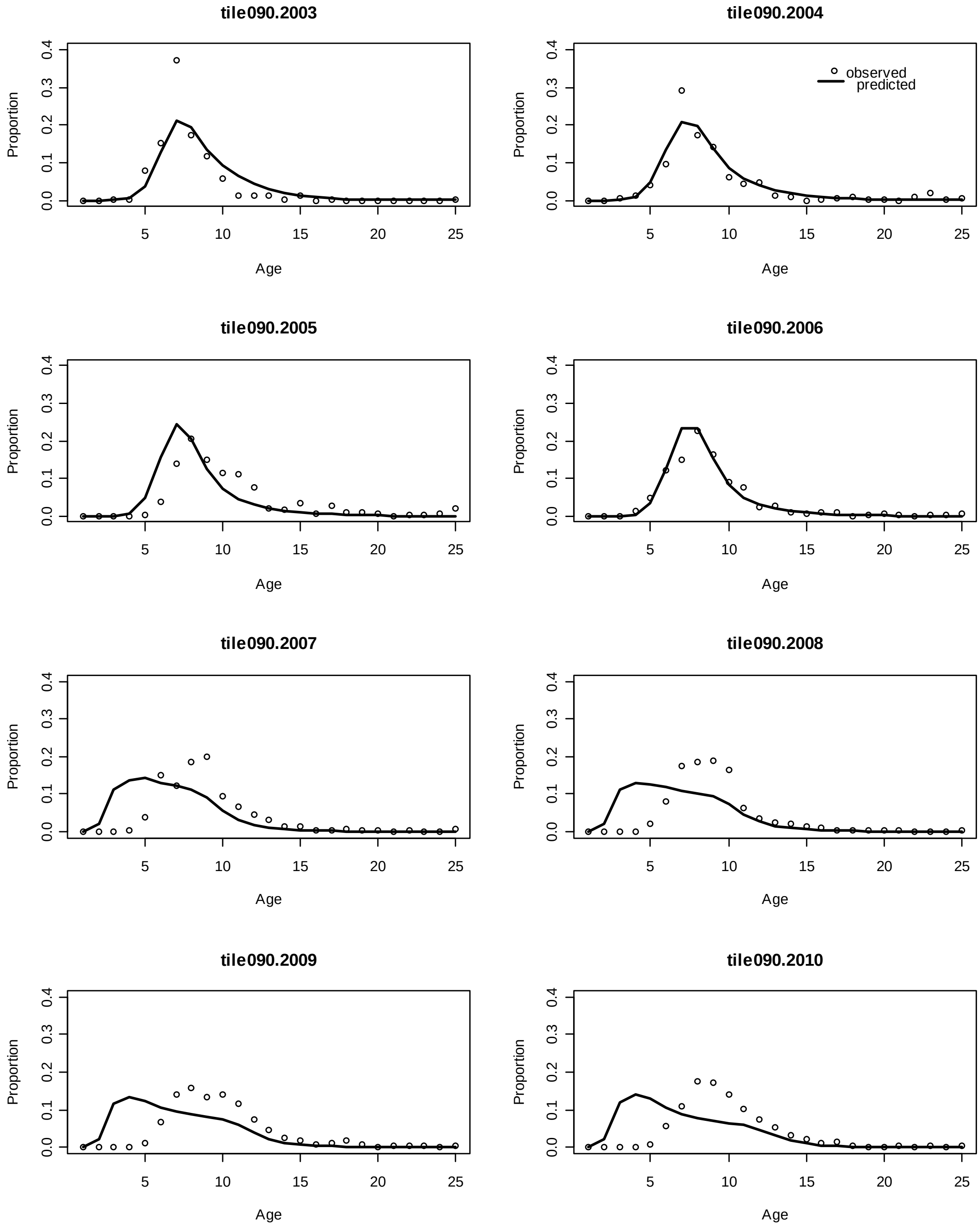


Figure 9 B.

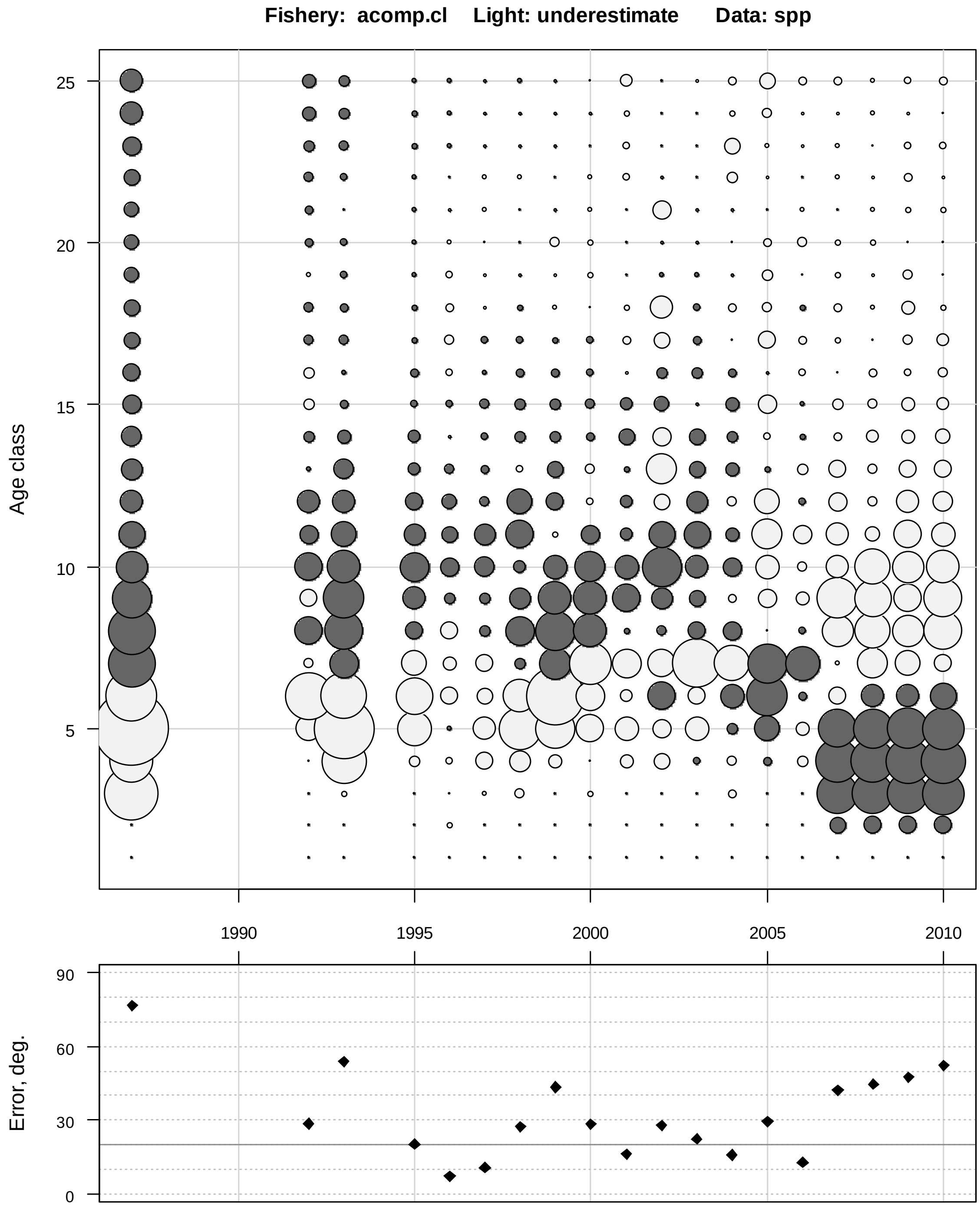

Fishery: acomp.cl Light: underestimate Data: spp
Age class
25
20
15
10
5
1990
1995
2000
2005
2010
Error, deg.
90
60
30
0

Figure 10. Fit of the base run, modified with two periods of logistic selectivity for commercial longlines starting in 2007 (tile091, s13), to the commercial longline age composition for 2003-10 (A) and deviations of the fit to the age composition (B).

A.

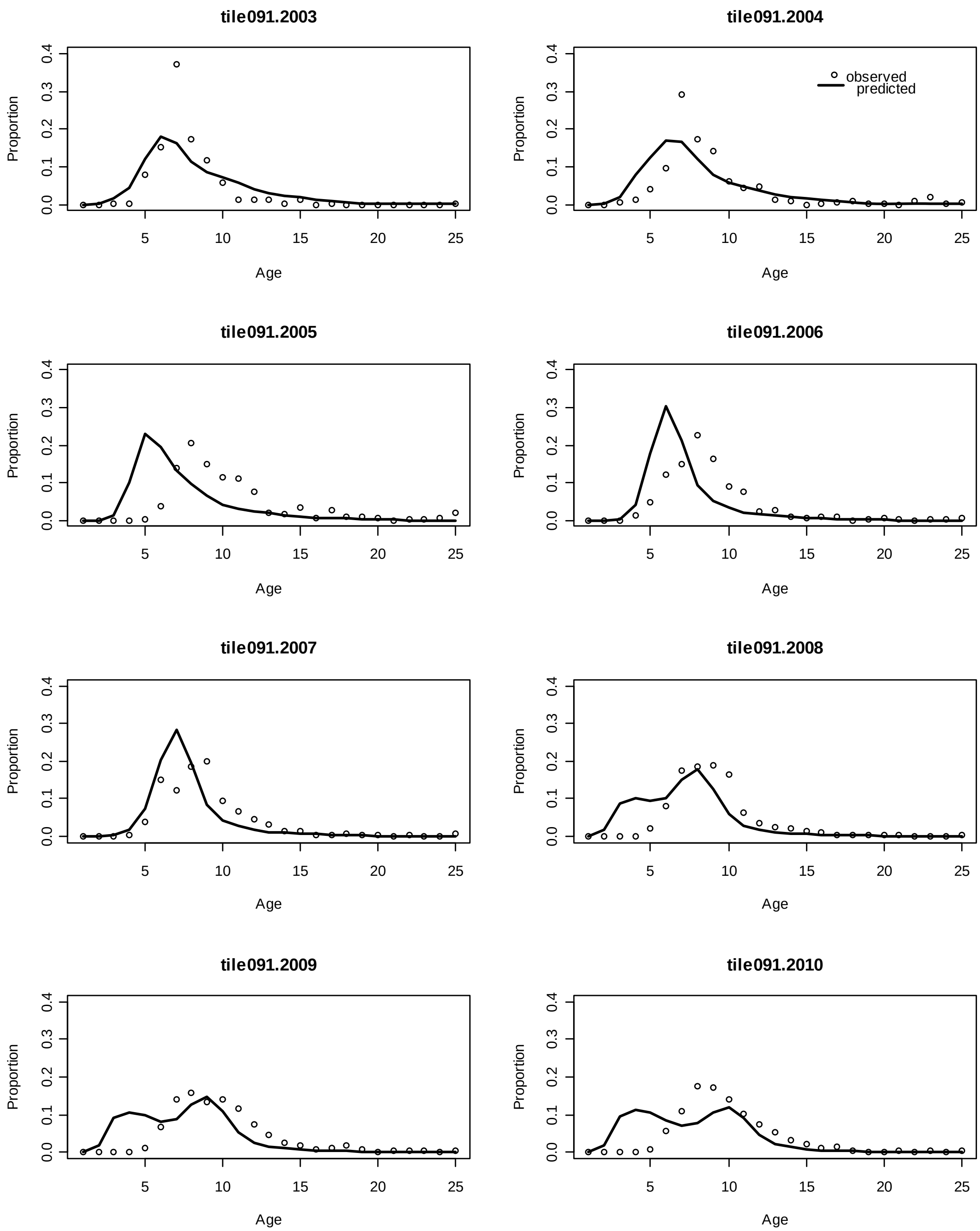


Figure 10 B.

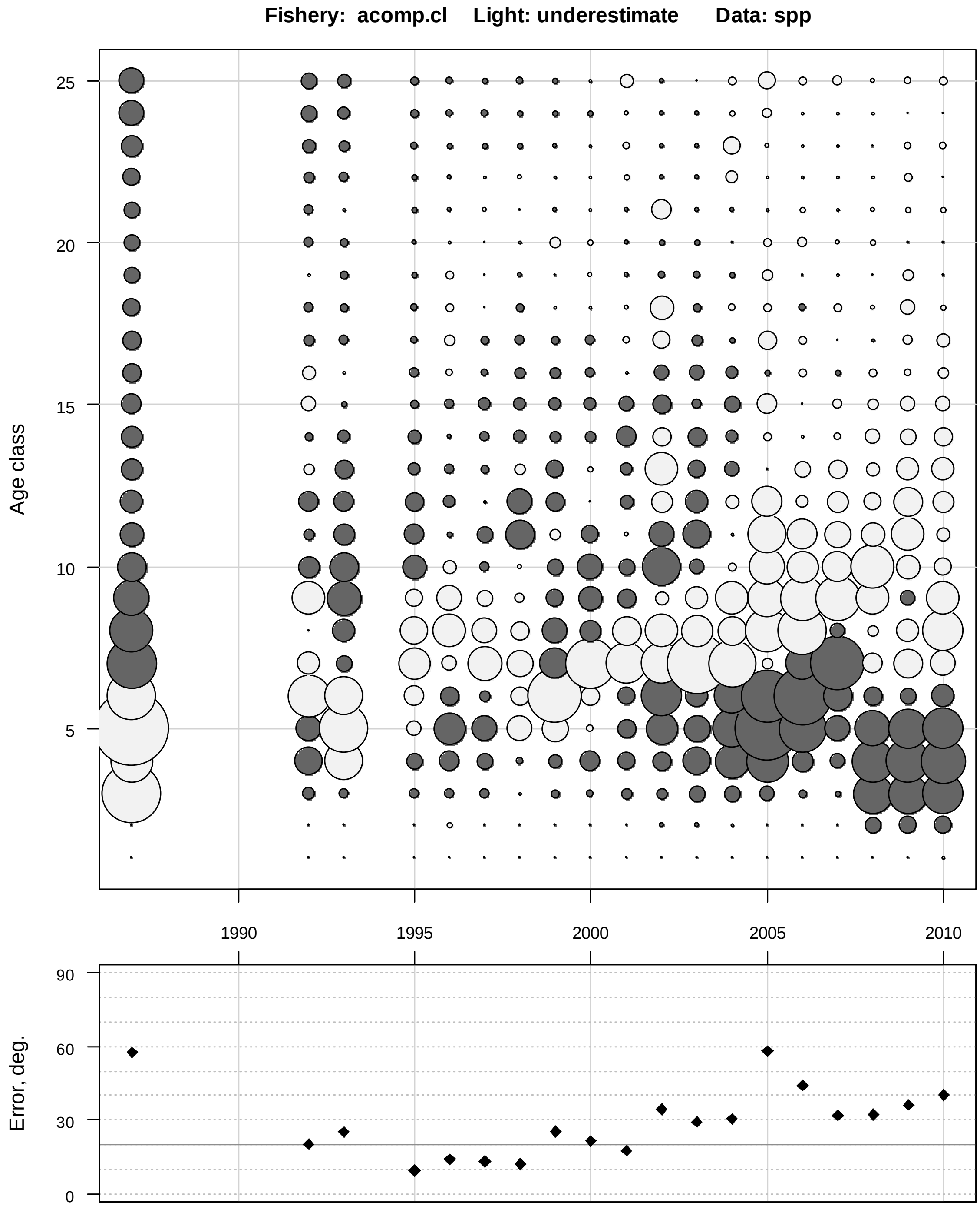

Fishery: acomp.cl Light: underestimate Data: spp
Age class
Error, deg.
25
20
15
10
5
1990
1995
2000
2005
2010
90
60
30
0

Figure 11. Fit to the commercial longline index with annually varying selectivity curves for 1995-2010.

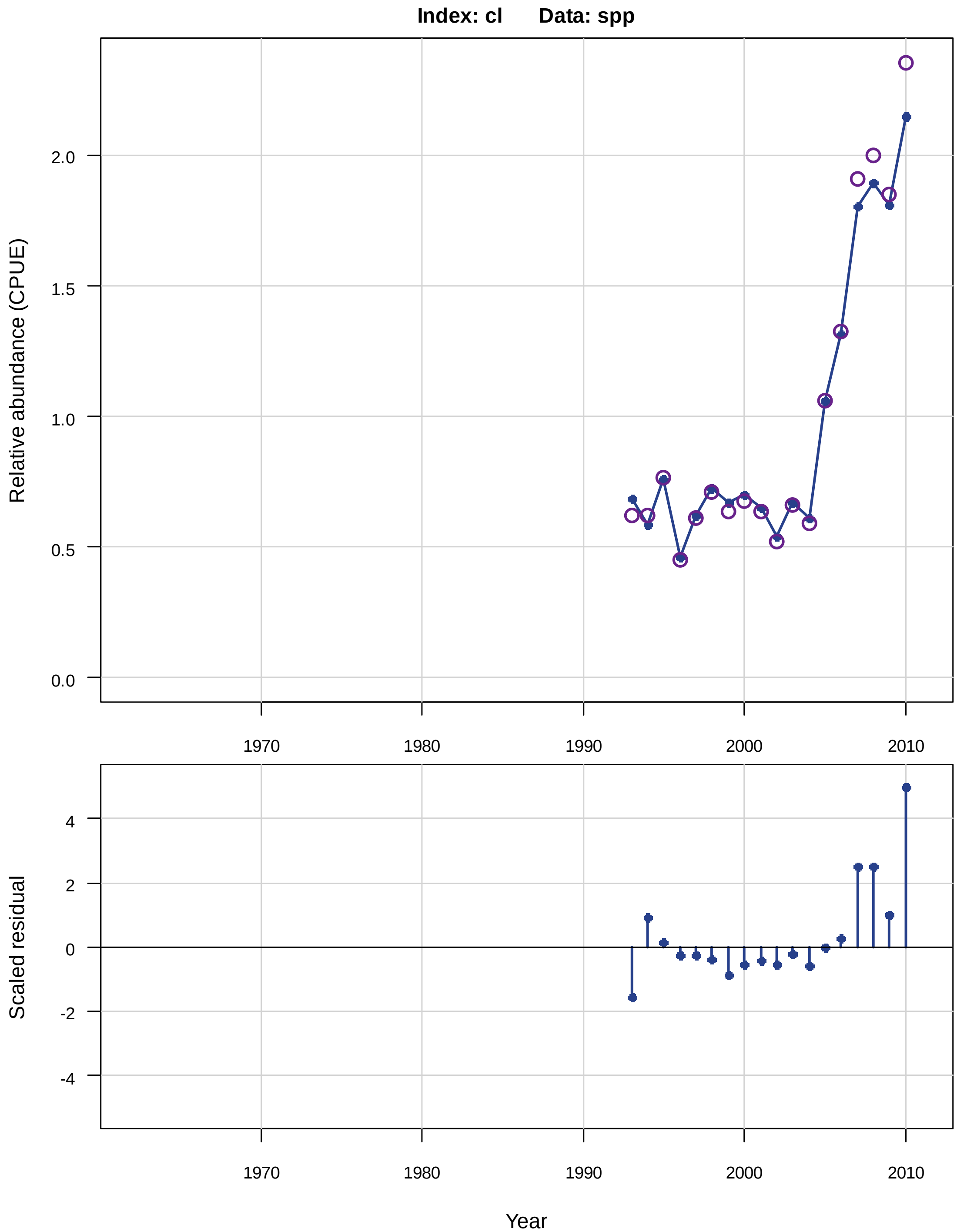


Figure 12. Fit of the base run, modified with annual varying selectivity for 1995-2010 (tile087), to the commercial longline age composition for 2003-10.

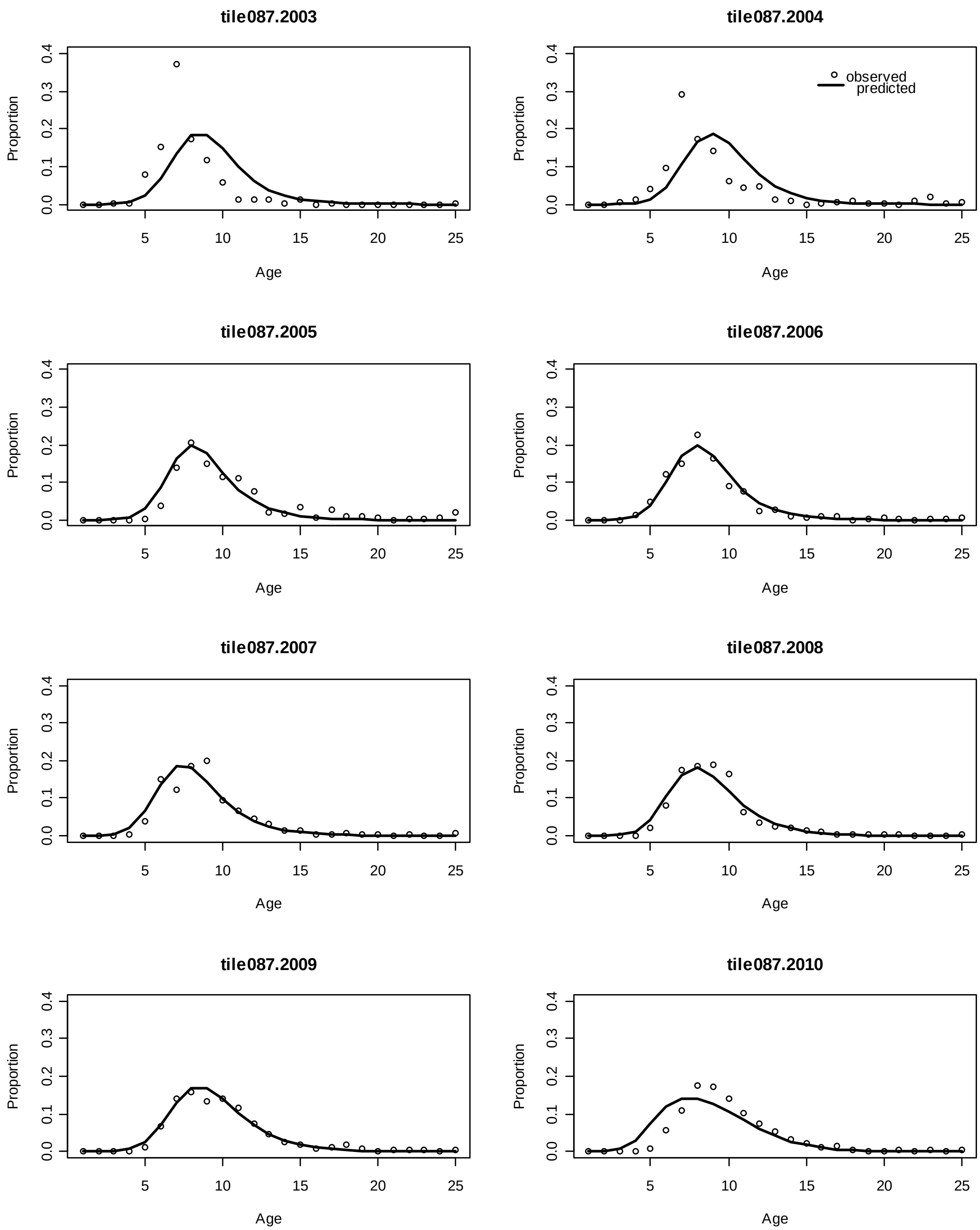


Figure 13. Fit of the base run, modified to exclude ageing error (tile095), to the commercial longline age composition for 2003-10 (A) and deviations of the fit to the age composition (B).

A.

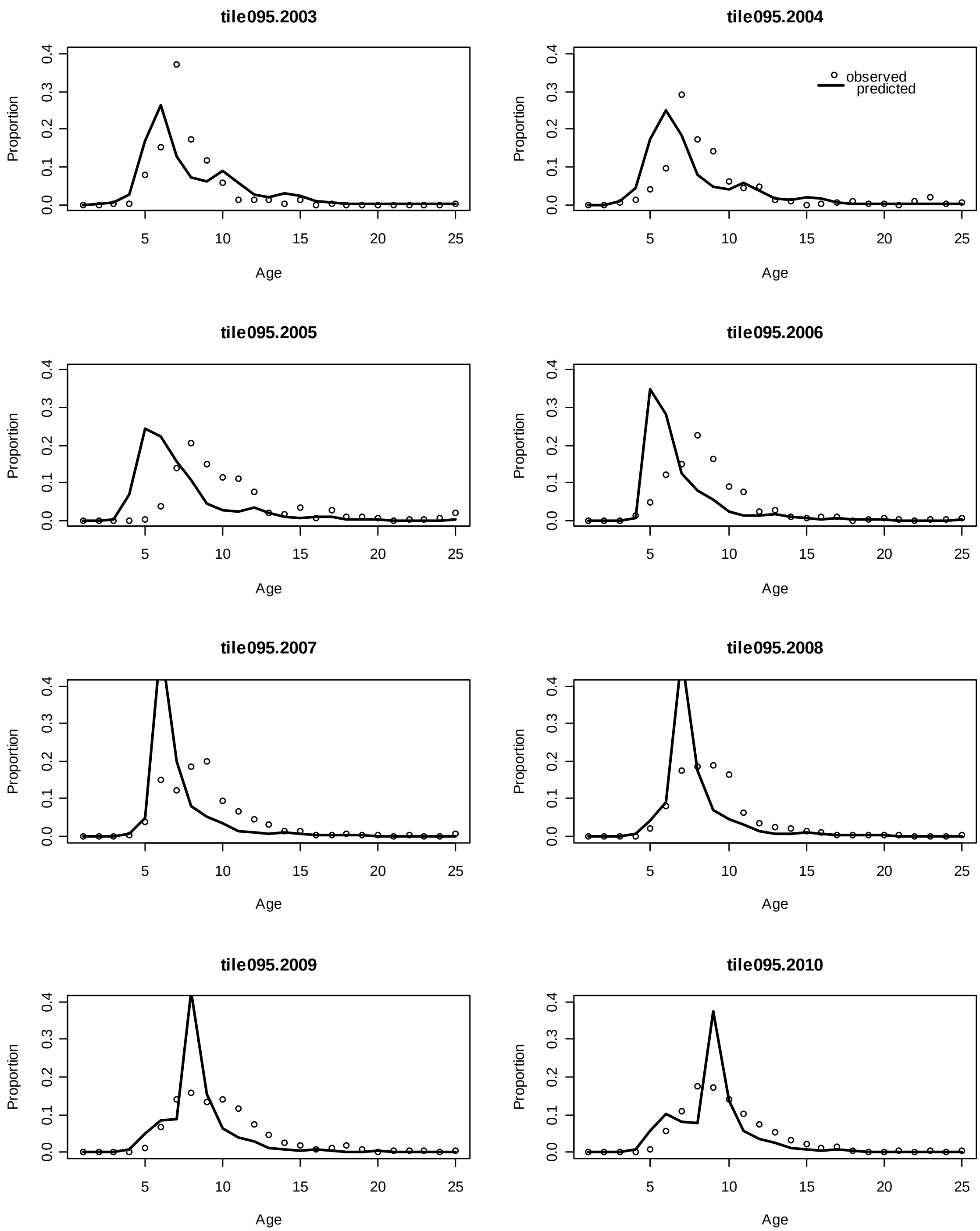


Figure 13 B.

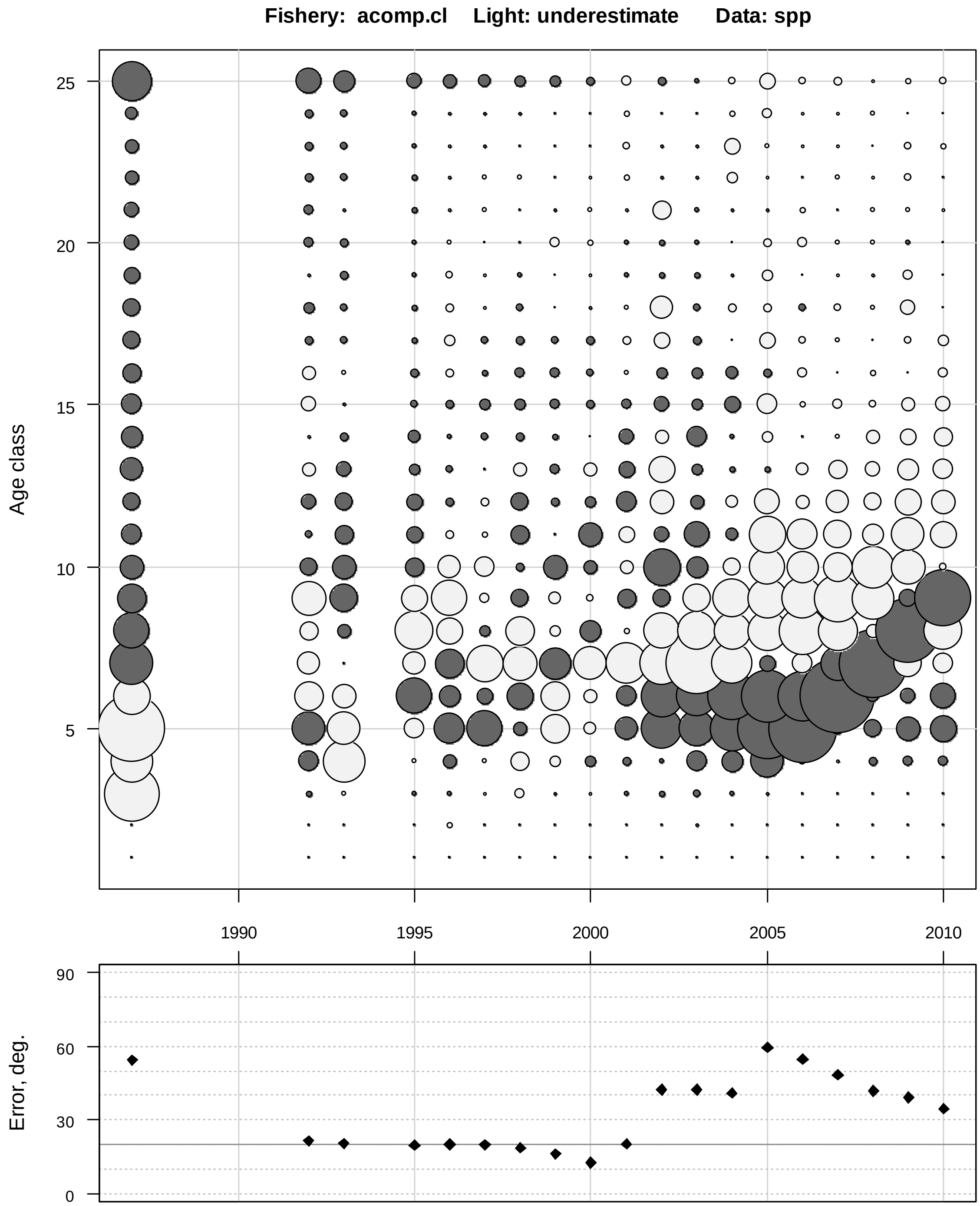

Fishery: acomp.cl Light: underestimate Data: spp
Age class
25
20
15
10
5
1990
1995
2000
2005
2010
Error, deg.
90
60
30
0

Figure 14. Predicted recruitment time series for the base run modified by dropping the commercial handline age composition data (tile094).

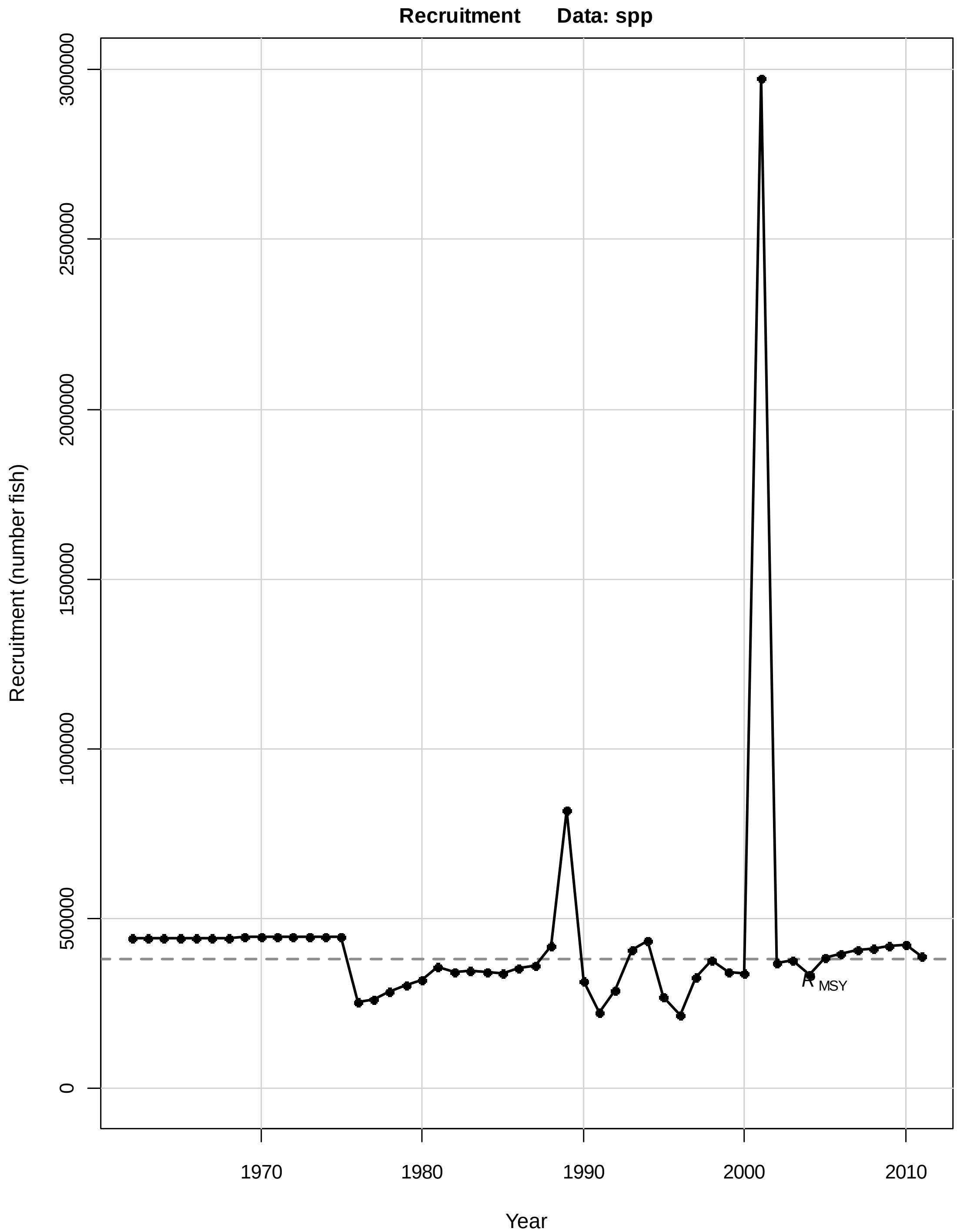


Figure 15. Recruitment time series (A) of the base run, modified by dropping the 2004-06 commercial longline age compositions (tile093, s16), and deviations of the fit to the remaining age composition data (B).

A.

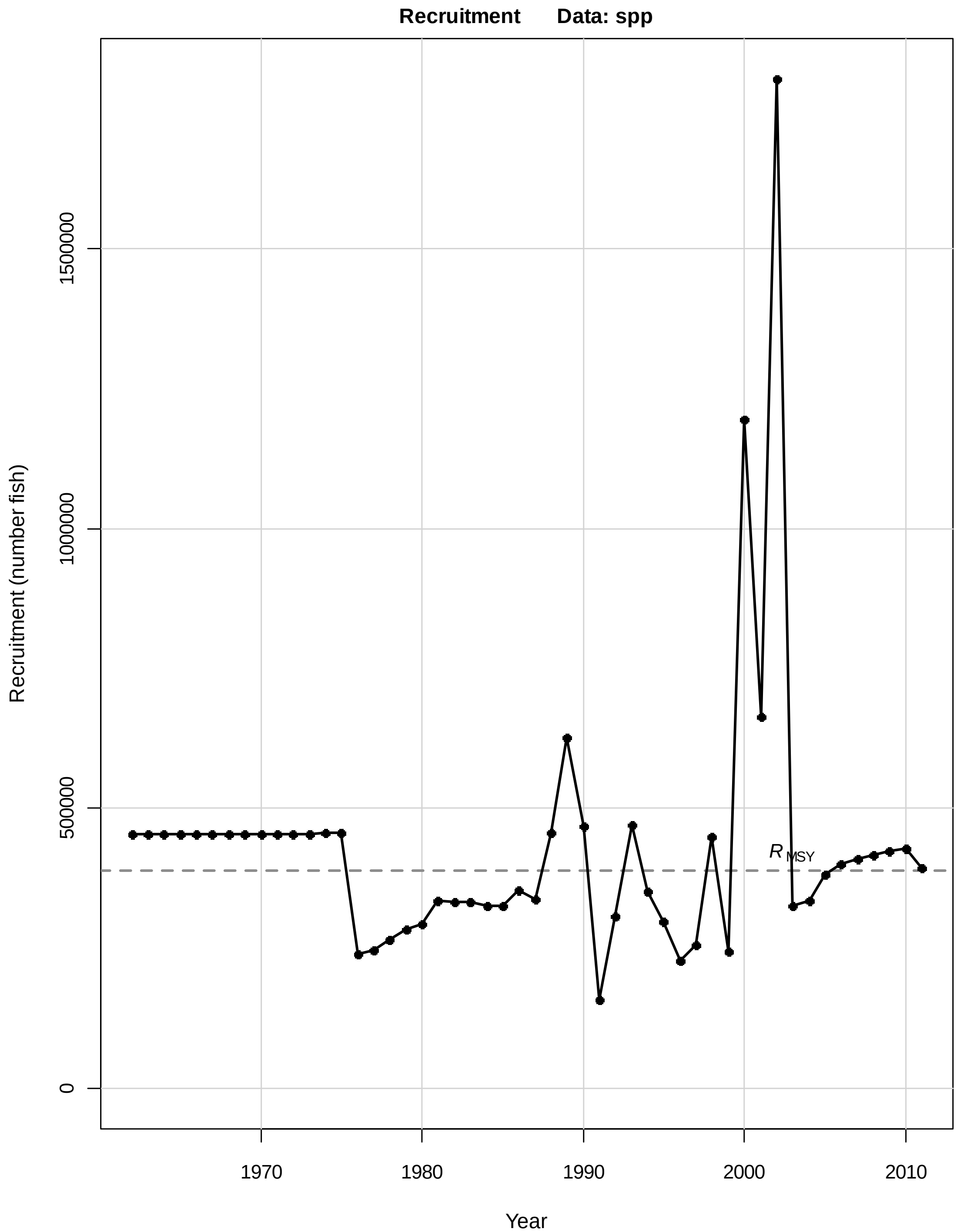


Figure 15 B.

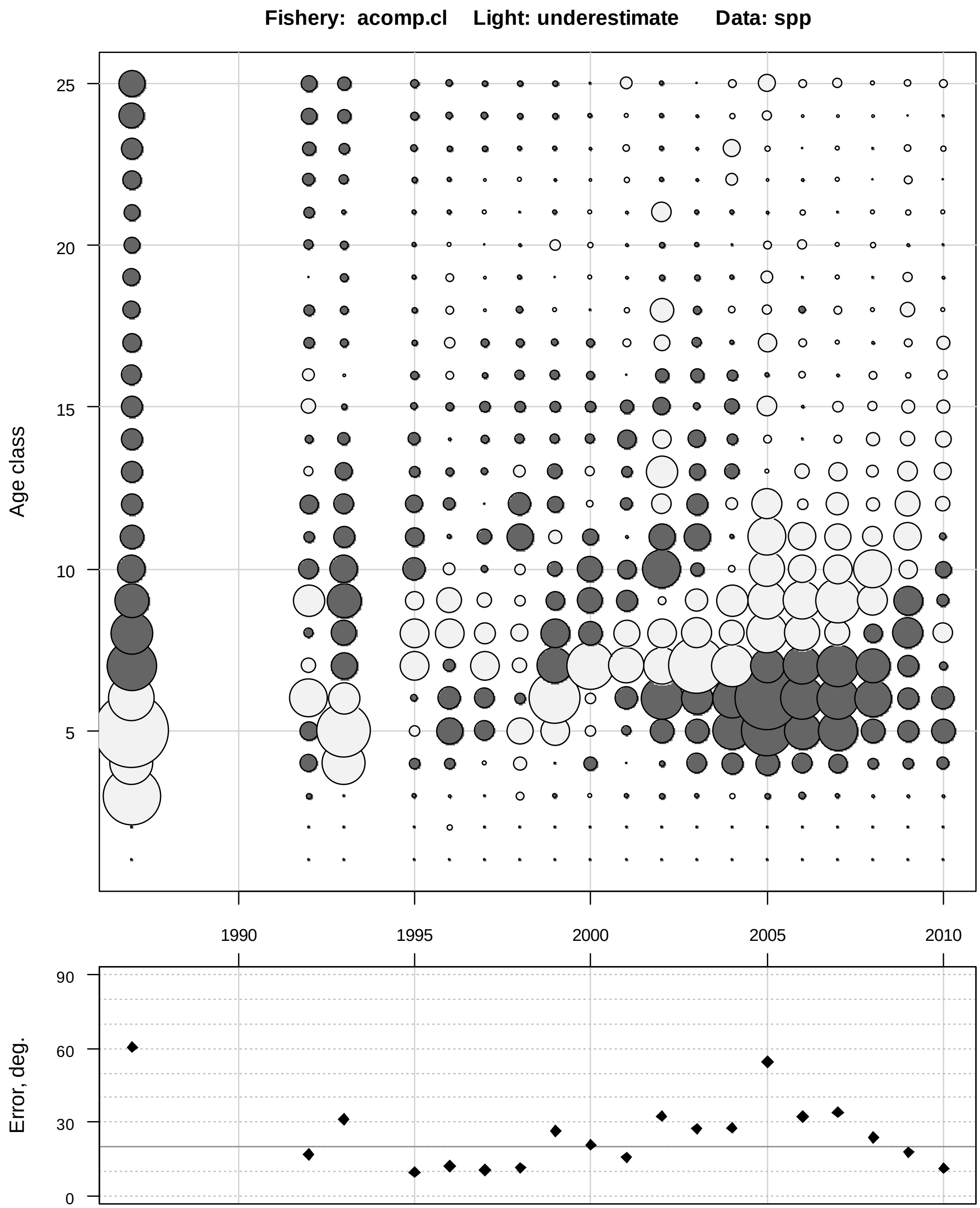

Fishery: acomp.cl Light: underestimate Data: spp
Age class
25
20
15
10
5
1990
1995
2000
2005
2010
Error, deg.
90
60
30
0

Figure 16. Top panel: bubble plots of length (lcomp) or age (agec) composition residuals by fleet or survey; blue (dark) represents overestimates and pink (light) represents underestimates. The size of bubbles within each data set is scaled to the largest residual. Bottom panel: angle (in degrees) between vectors of observations and estimates, with a reference line at 20 degrees; this measure of error is bounded between 0 and 90 degrees, with 0 indicating a perfect fit. Data set indicated above each set of bubble plots: lcomp=length compositions, acomp=age compositions, mm=MARMAP longline survey, cl=commercial longline, ch=commercial handline, ra=general recreational.

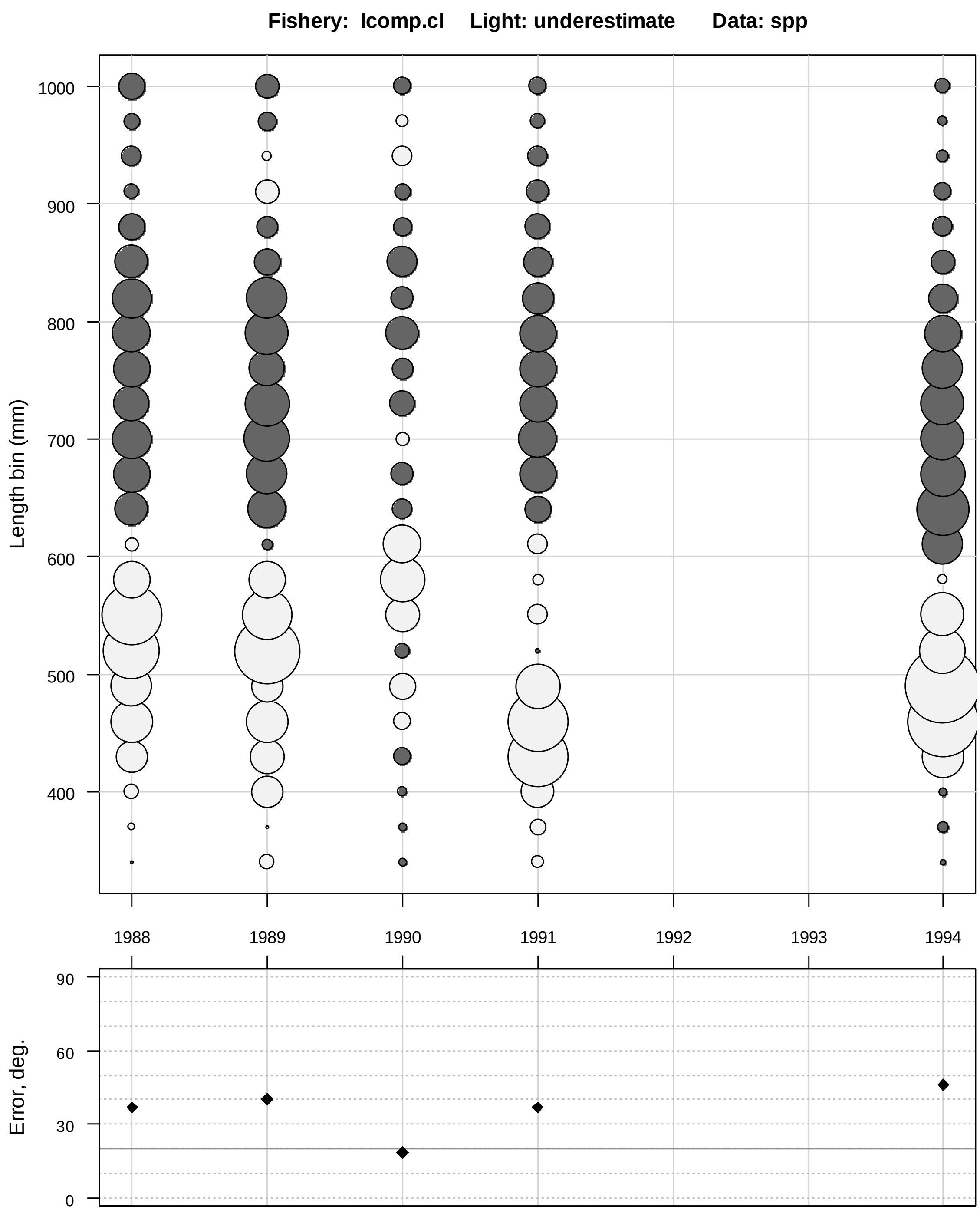


Figure 16 (cont.)

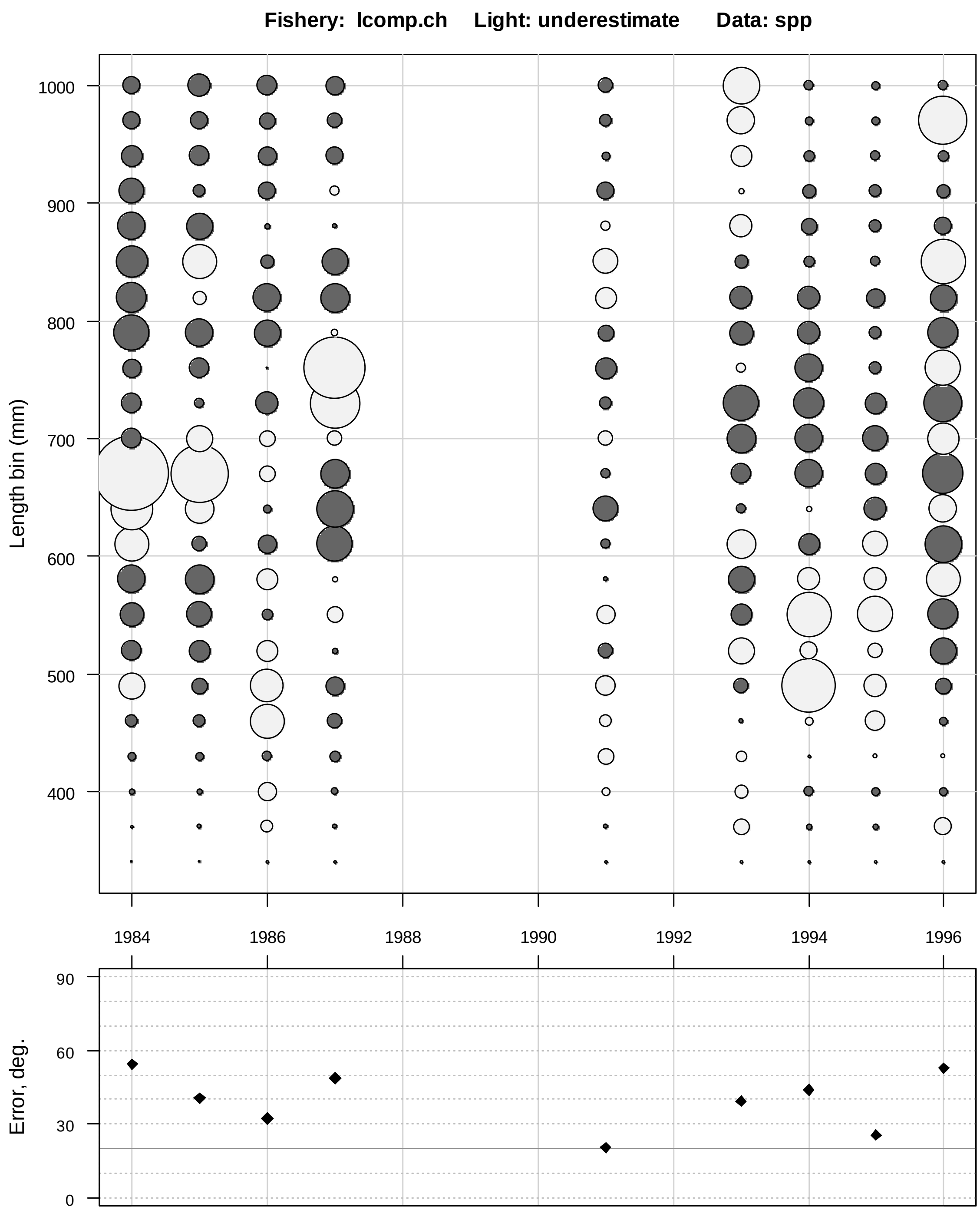


Figure 16 (cont.)

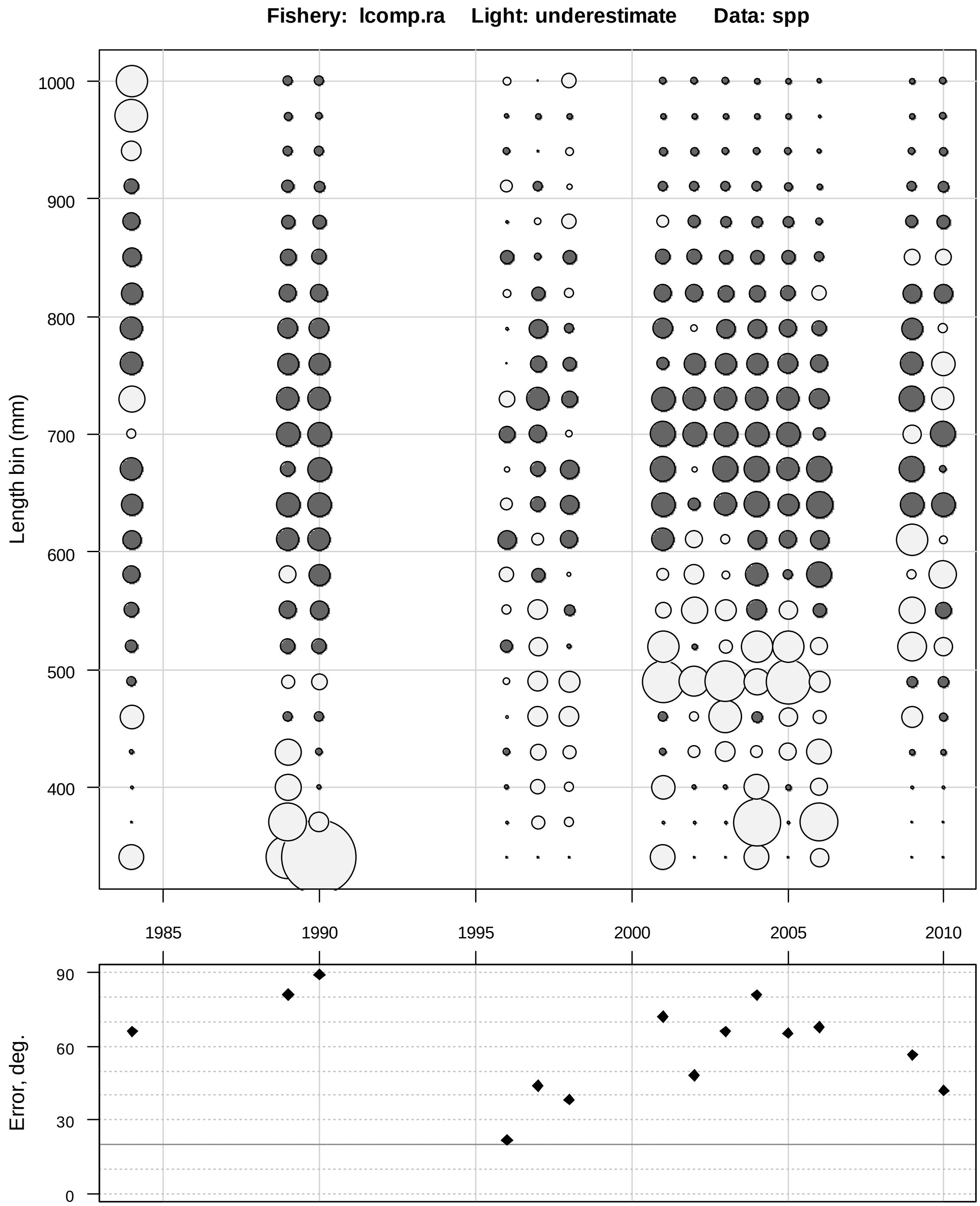


Figure 16 (cont.)

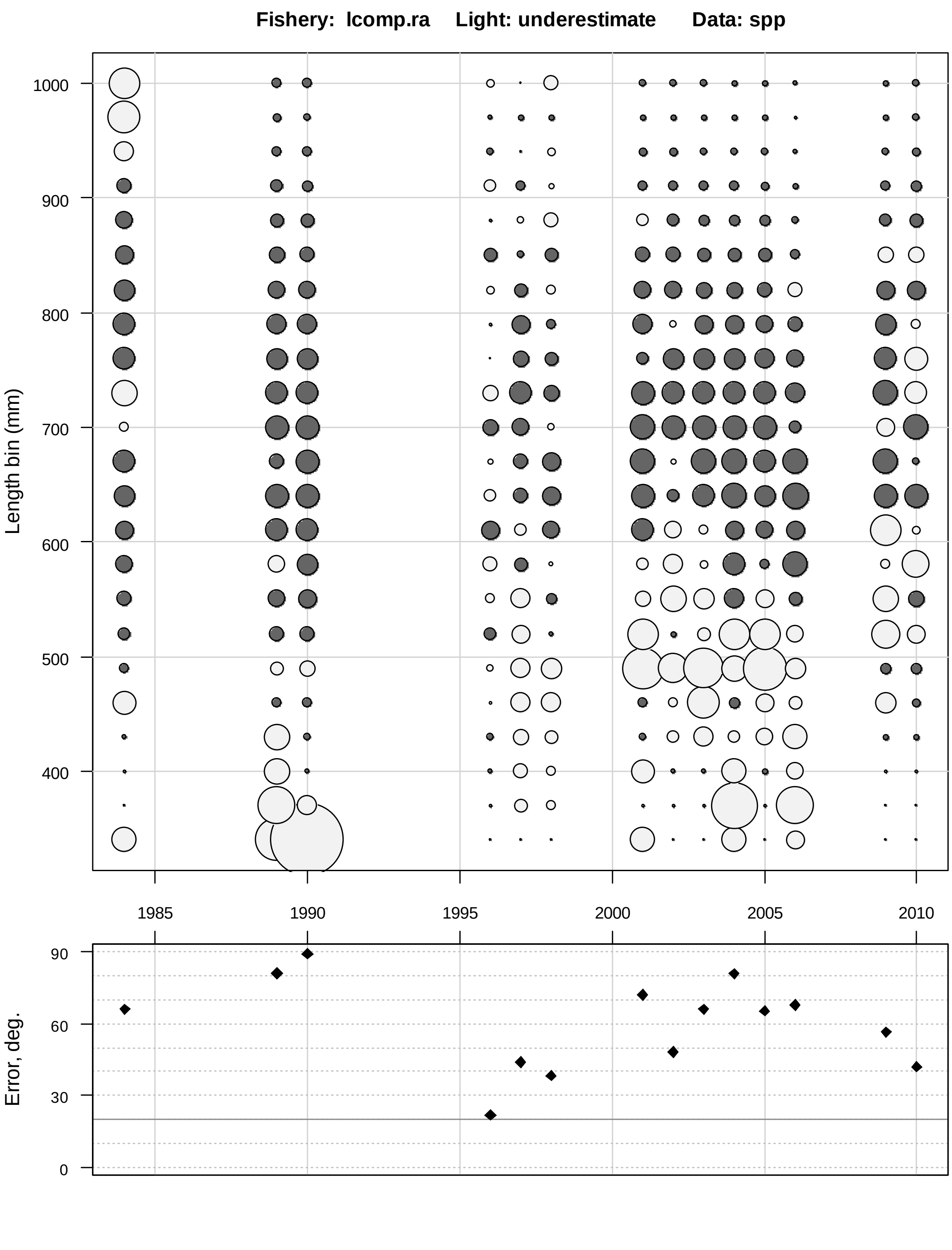


Figure 16 (cont.)

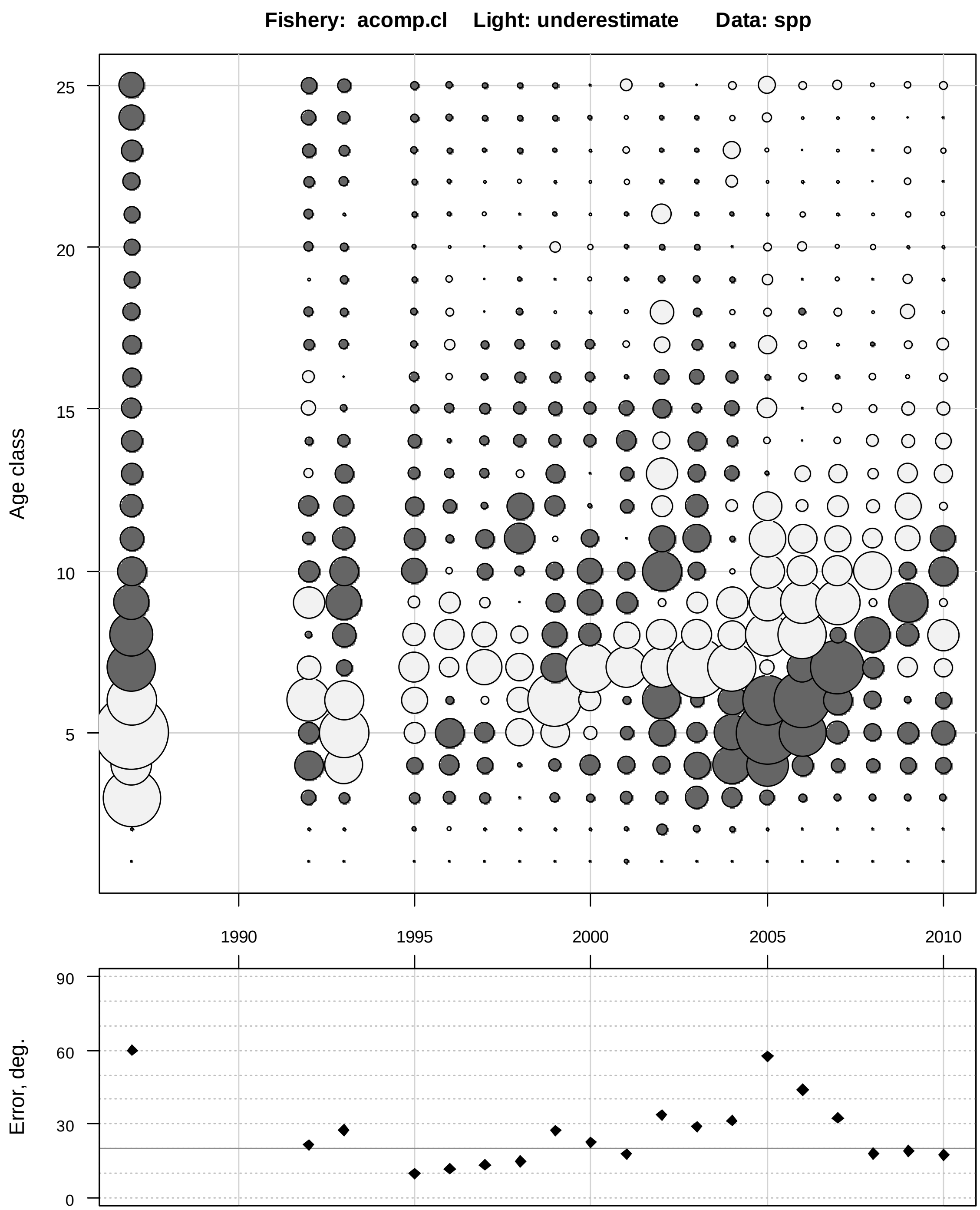


Figure 16 (cont.)

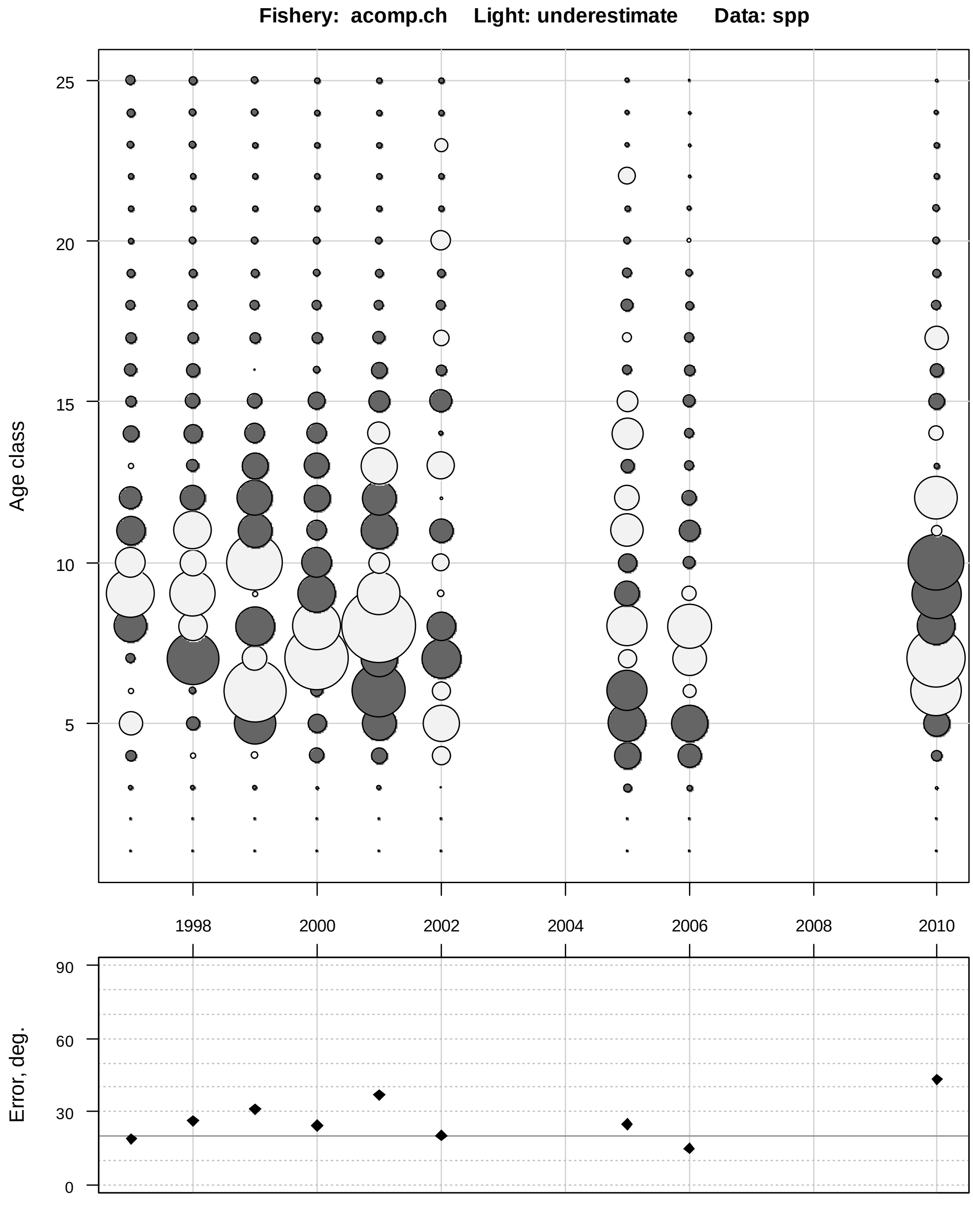


Figure 16 (cont.)

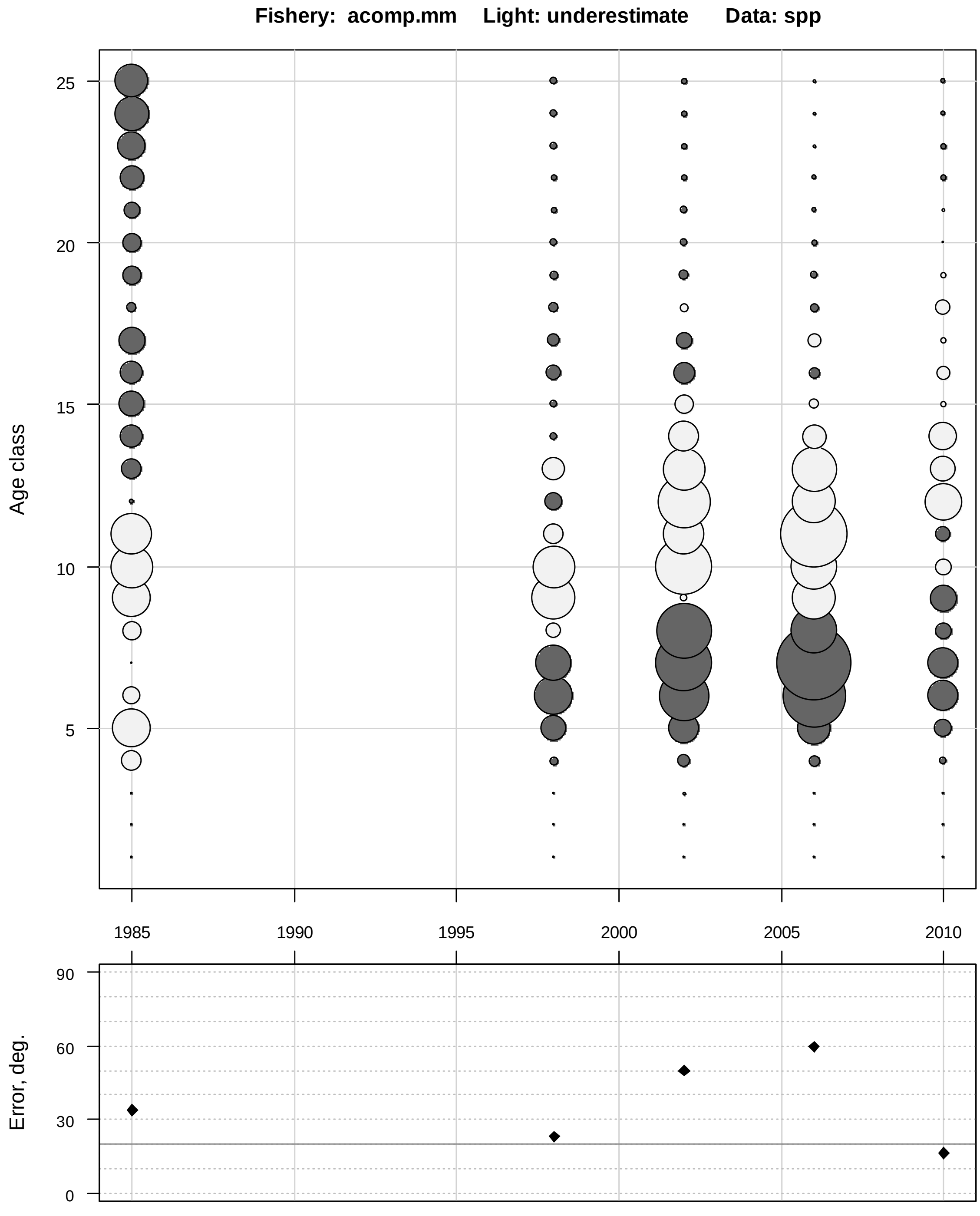


Figure 17. Standardized proportions at year (SPAY) plots. Light gray indicates above average proportion at age, black indicates below average proportion at age. The size of bubbles within each data set is scaled to the largest values. As indicated above the panels, spay plots are shown for predicted abundance, as well as for observed and predicted catches from fleets with suitably long time series of catch at age.

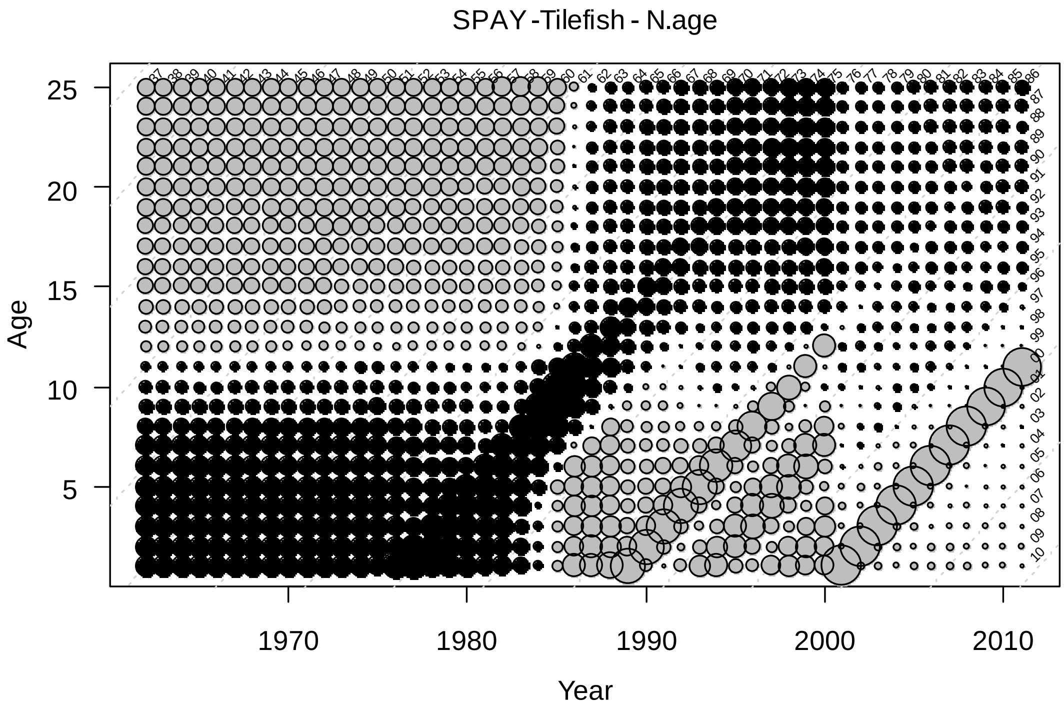


Figure 17 (cont.)

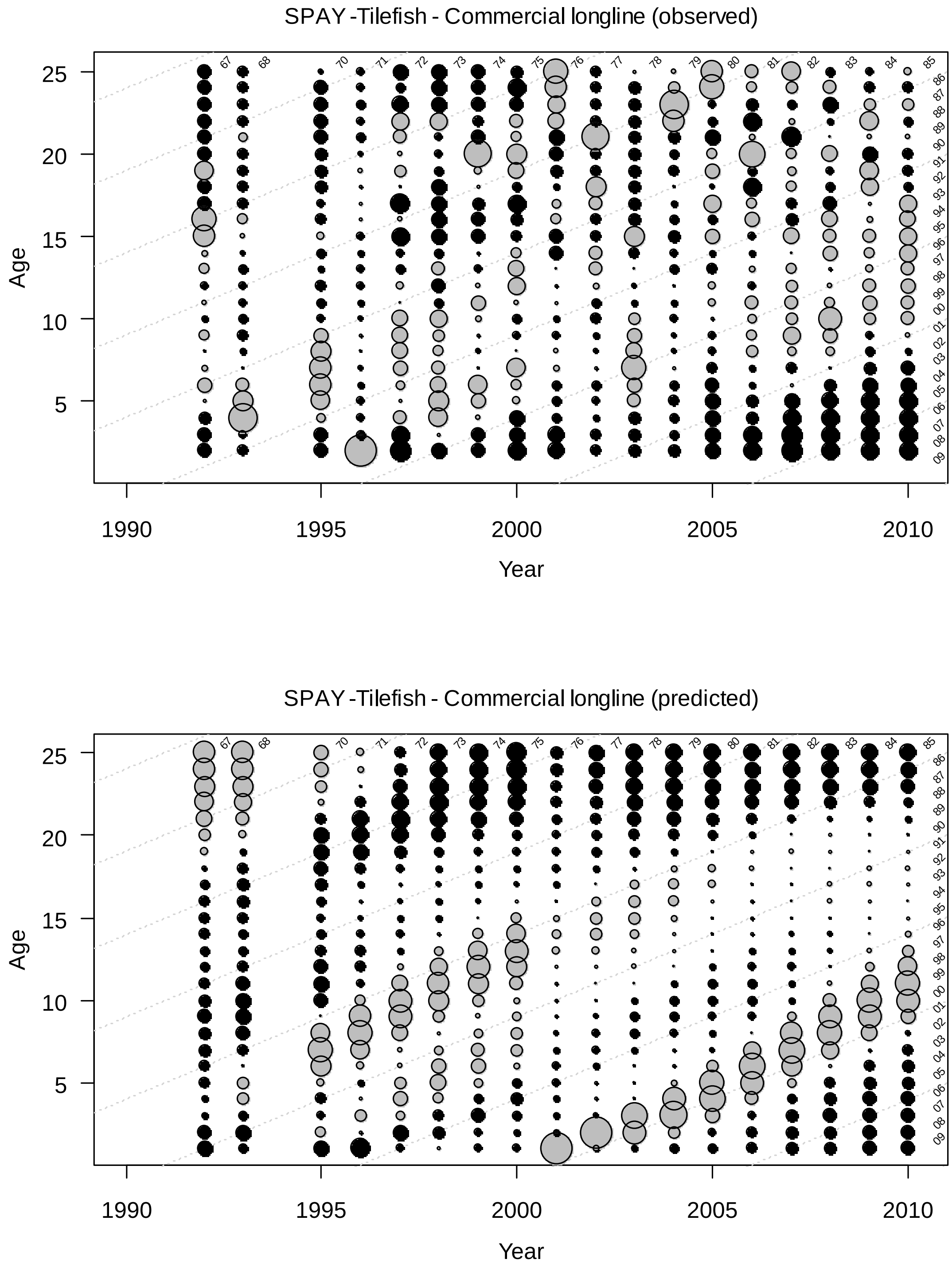
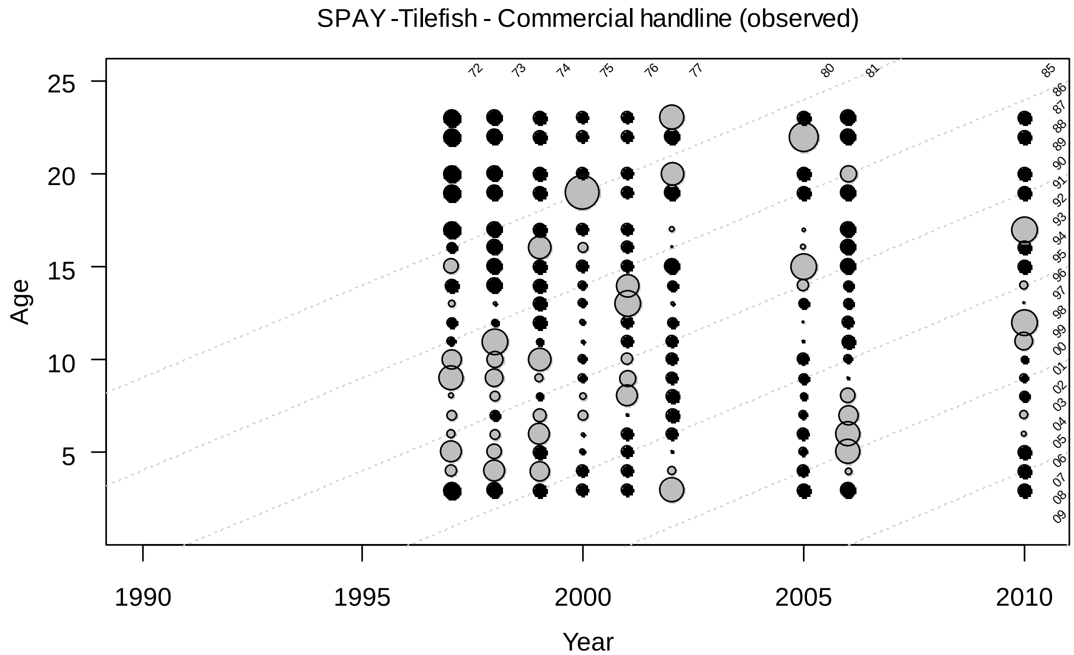


Figure 17 (cont.)



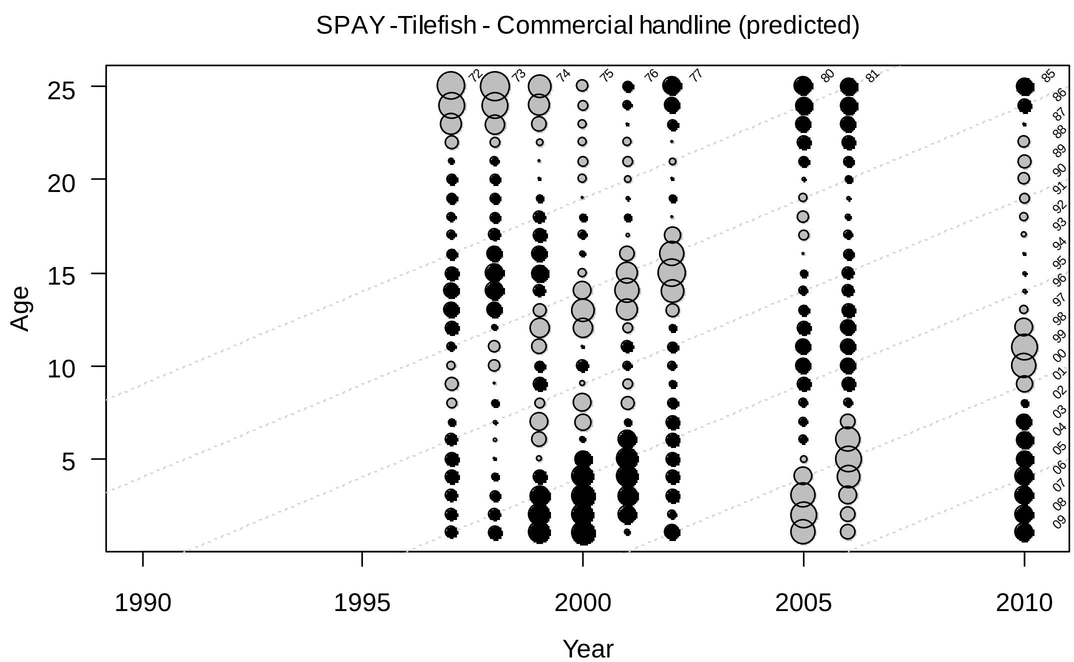
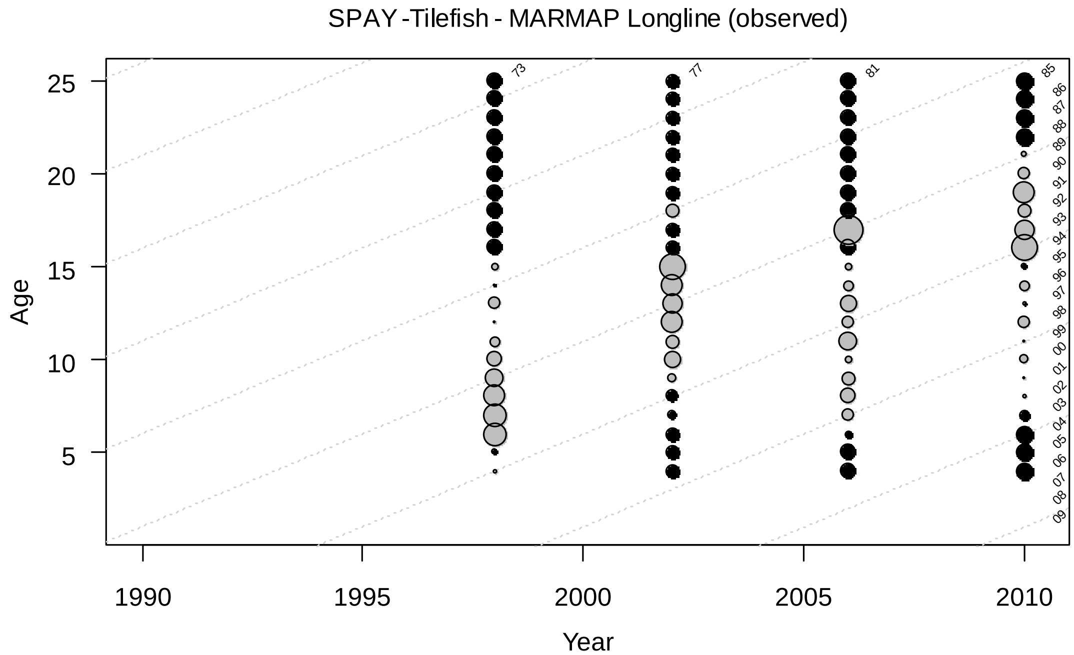


Figure 17 (cont.)



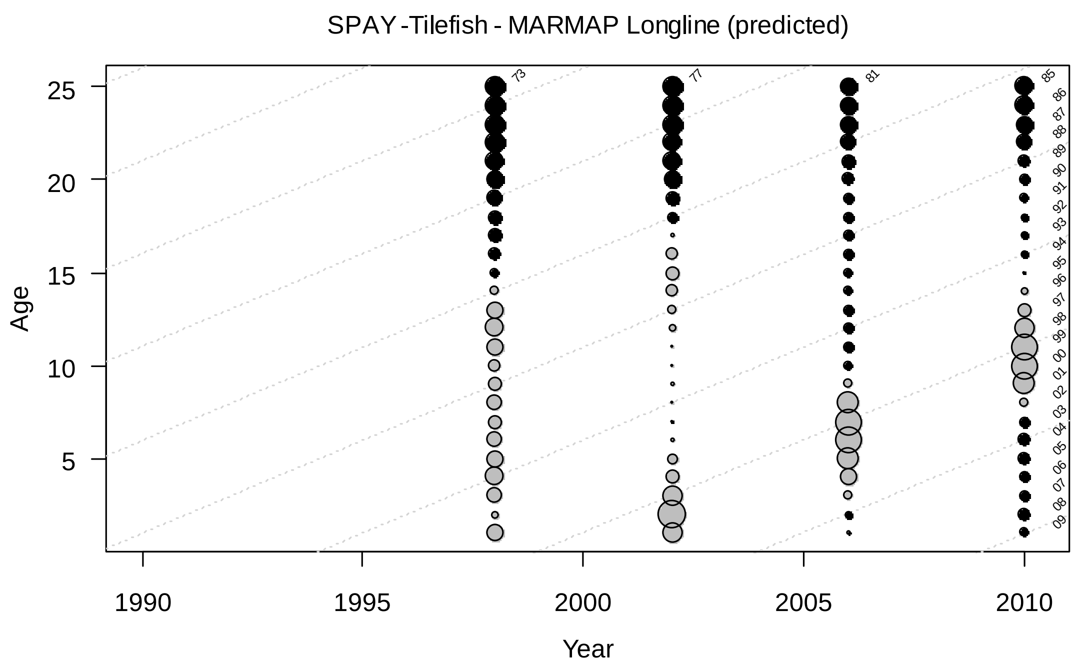


Figure 18. Total and component likelihood profiles on steepness, R0, and natural mortality. The likelihood components are commercial longline CPUE index (U.cl), MARMAP CPUE index (U.mm), commercial longline length composition (lenc.cl), commercial handline length composition (lenc.ch), commercial longline age composition (agec.cl), commercial handline age composition (agec.ch), MARMAP age composition (agec.mm), and the stock-recruit deviations (SR.fit).

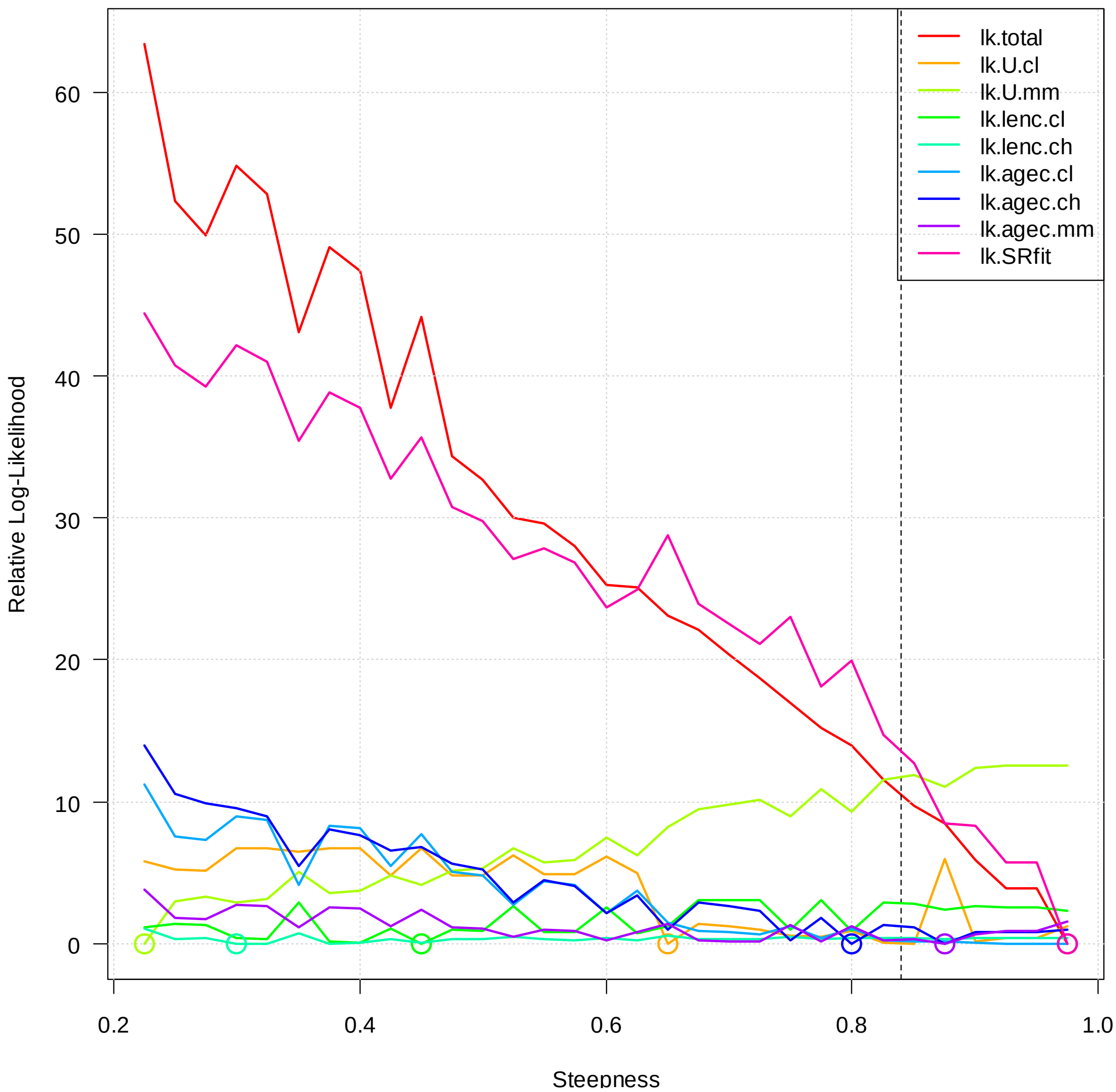


Figure 18 (cont.)

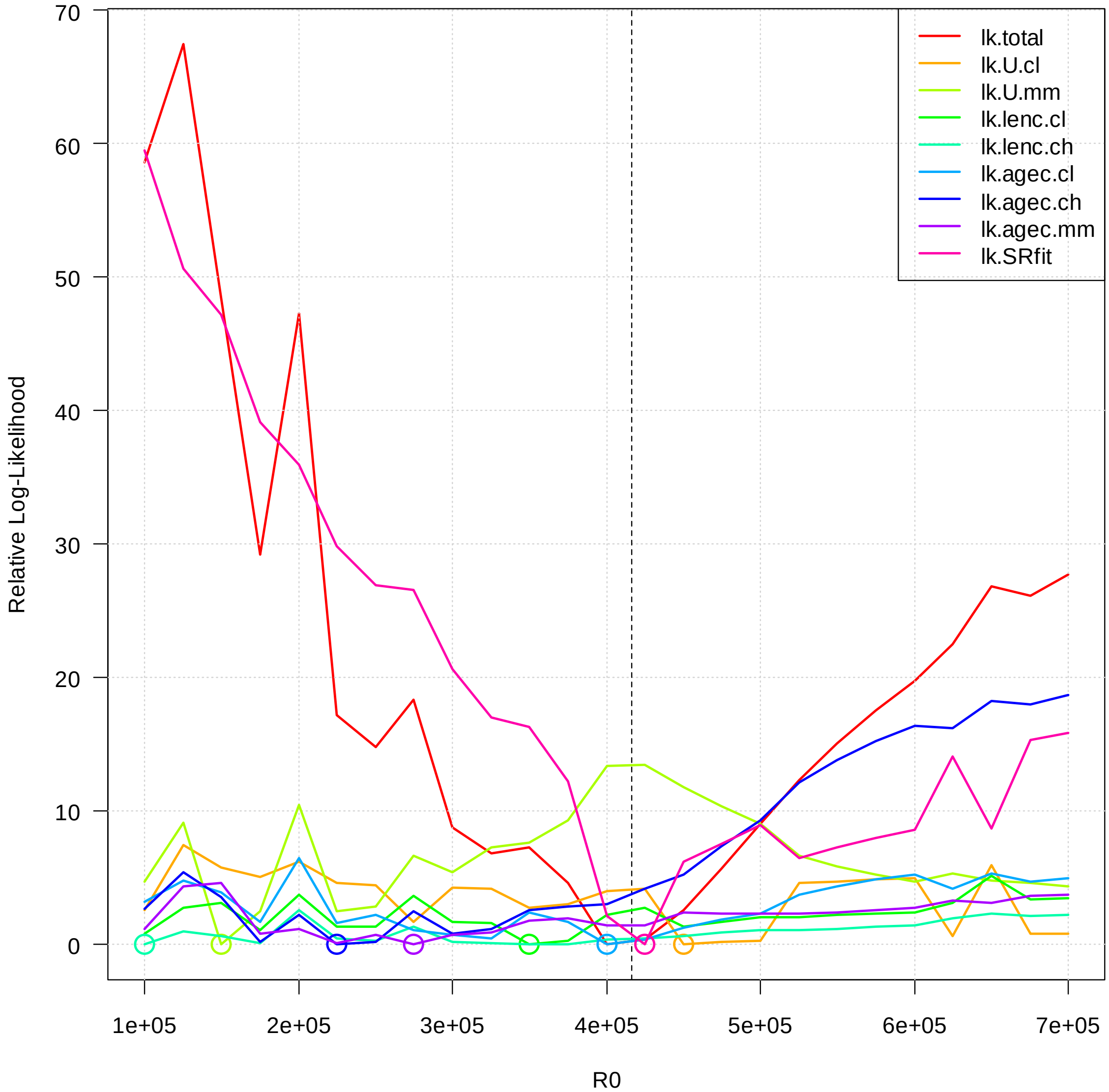


Figure 18 (cont.)

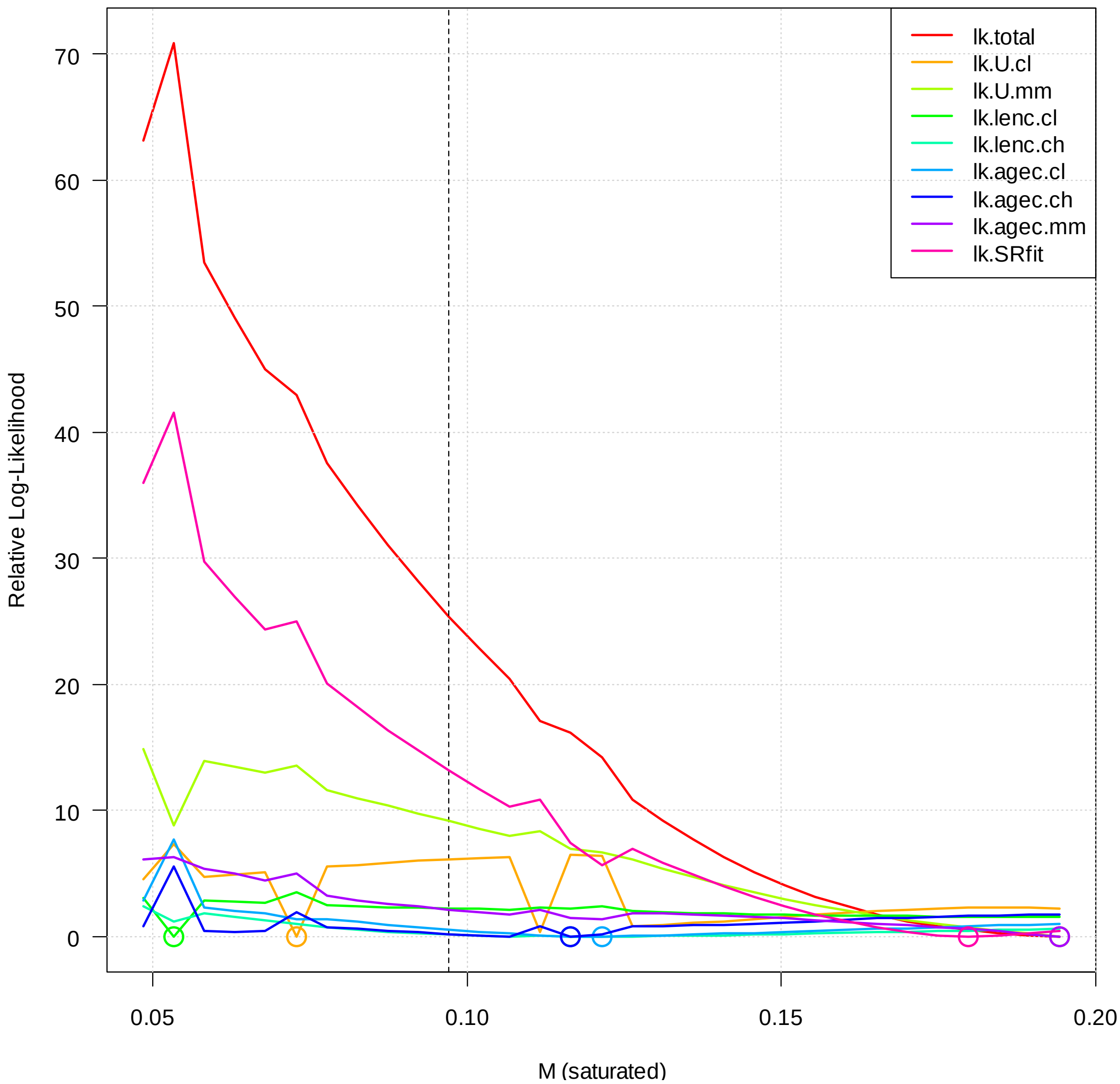
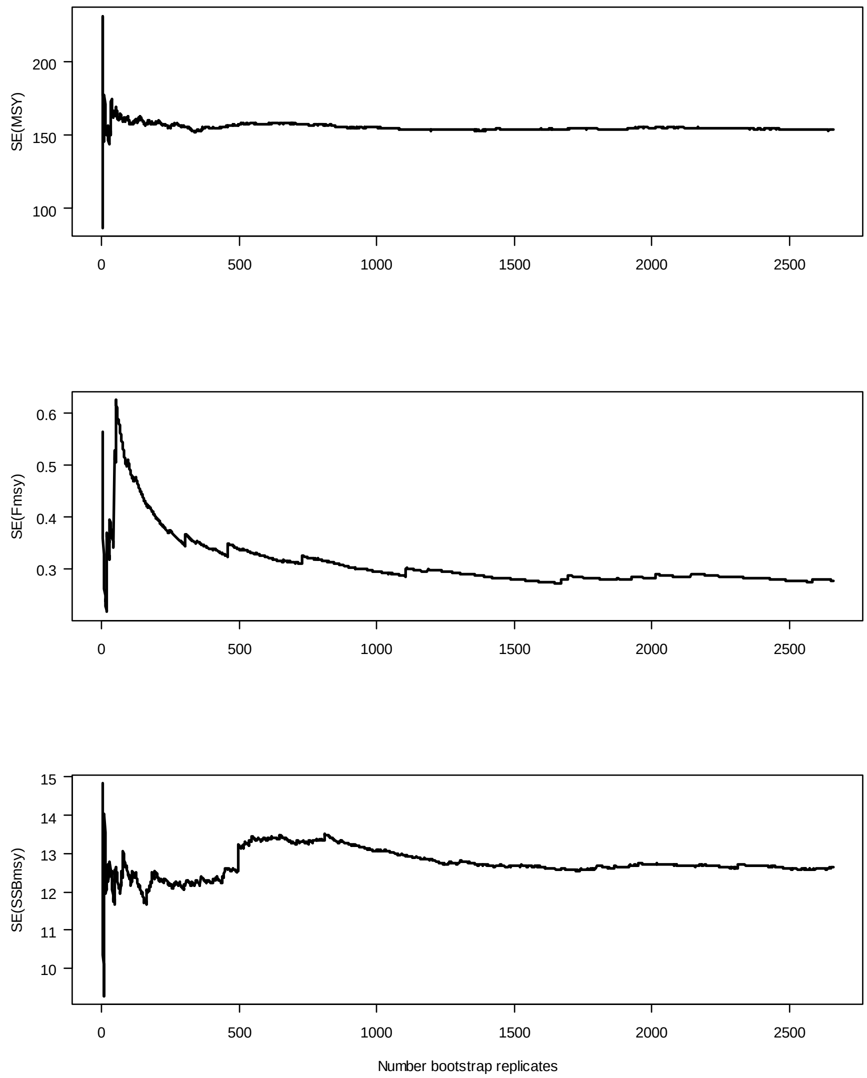


Figure 19. Standard errors of management quantities as a function of the number of Monte Carlo/bootstrap iterations.



Appendix 1. Description of model runs leading to the base run and sensitivity runs altered from the base run.

Run	Sensitivity Run (AW Report)	Description (cl-commercial longline, ch-commercial handline, ra-recreational)
tile004		initial run, all like wgts set to 1.0 (except landings = 10.0), all years rec devs estimated, assume start = virgin
tile005		skip
tile006		same as tile004, start rec devs in 1974
tile007		same as tile006, increase penalty on ending rec devs (10.0) (2005-2010 devs)
tile008		same as tile007, turn off autocorr parameter
tile009		same as tile008, turn on prior on rA sel parms (does not work well)
tile010		same as tile009, fix rA sel parms
tile011		same as tile010, increase wgt on cL index (5.0)
tile012		same as tile011, turn on priors for steepness and len_cv
tile013		same as tile012, steep fixed (0.75)
tile014		same as tile013, drop ending yr rec devs estimation, added endyr_rec_dev parameter to code, turned off ending yr rec devs constraint
tile015		skip
tile016		AW starting run, added log-log gonad wgt function, start at 0.9 virgin, start rec devs in 1976, fix sel_ra = sel_cH, drop rA length comps from estimation
tile017		same as tile016, M=M*1.5
tile018		same as tile017, M=M*2.0
tile019		same as tile018, annual deviation for L50_cL added
tile020		same as tile017, annual deviation for L50_cL added
tile021		same as tile016, constant catchability, free up ending rec devs
tile022		same as tile016, add 2nd period for sel_cL
tile023		same as tile016, constant catchability
tile024		same as tile023, fix steepness at 0.84, correct age data, fixed BiasCor code in last years
tile025		same as tile024, step one iterative re-weighting
tile026		same as tile025, step two iterative re-weighting
tile027		same as tile026, step three iterative re-weighting
tile028		same as tile027, step four iterative re-weighting
tile029		same as tile028, final iterative re-weighting
tile030		same as tile029, wgt on cL index = 1.0
tile031		same as tile029, wgt on cL index = 1.5
tile032		same as tile029, wgt on cL index = 2.0
tile033		same as tile029, wgt on cL index = 2.5
tile034		same as tile029, wgt on cL index = 3.0
tile035		same as tile029, wgt on cL index = 3.5
tile036		same as tile029, wgt on cL index = 4.0

tile037		same as tile029, wgt on cL index = 4.5
tile038		same as tile029, wgt on cL index = 5.0
tile039		same as tile034, autocorr = 0.25
tile040		same as tile034, set w_SR = 0.01, autocorr = 0.0
tile041		same as tile040, autocorr freely estimated
tile042		same as tile041, set w_SR = 0.001
tile043		same as tile034, [old base run] add aging error based on 0.5 * GOM sd's at age
tile044		same as tile043, aging error bsed on 0.1 * GOM sd's at age
tile045		same as tile043, aging error bsed on 0.2 * GOM sd's at age
tile046		same as tile043, aging error bsed on 0.3 * GOM sd's at age
tile047		same as tile043, aging error bsed on 0.4 * GOM sd's at age
tile048		same as tile043, aging error bsed on 0.6 * GOM sd's at age
tile049		same as tile043, aging error bsed on 0.7 * GOM sd's at age
tile050		same as tile043, aging error bsed on 0.8 * GOM sd's at age
tile051		same as tile043, aging error bsed on 0.9 * GOM sd's at age
tile052		same as tile043, aging error bsed on 1.0 * GOM sd's at age
tile053		same as tile043, priors on slopes of selectivity for cL, cH, and mm with 100% CV
tile054		same as tile053, [Old BASE RUN] slope parameter priors tightened to 50% CV, prior on Rsigma, increased Fmsy limit to 3.0
tile055		same as tile054, add constraint on last three years rec devs
tile056		same as tile055, add 2x constraint on last three years rec devs
tile057		same as tile056, add 4x constraint on last three years rec devs
tile058		same as tile056, add 8x constraint on last three years rec devs
tile054mcb		same as tile054, used in MCB
tile059		same as tile054, M = lower bound from DW
tile060		same as tile054, M = upper bound from DW
tile061		sames as tile054, steep = 0.94
tile062		same as tile054, steep = 0.74
tile063		sames as tile054, likelihood weights all set to 1.0
tile064		same as tile054, 2% increase in catchability for logbook index
tile065		same as tile054, drop the MARMAP index
tile066		same as tile054, drop the commercial logbook index
tile067		same as tile054, increase wgt on SR resids to 10.0
tile068		same as tile054, without aging error
tile069		same as tile054, add constraint for F exceeding 3.0
tile070		same as tile054, add constraint for F exceeding 0.6, but not in last phase
tile071		same as tile070, increase weight on constraint
tile072		same as tile054, fix R sigma = 0.4428
tile073		same as tile072, add constraint for F exceeding 0.6, but not in last phase
tile074		same as tile073, allow constraint to remain in all phases
tile075		same as tile074, F constraint = 1.0

tile076	Base Run	same as tile075, [BASE RUN] free R sigma parameter
tile077	S1	same as tile076, M = lower bound from DW
tile078	S2	same as tile076, M = upper bound from DW
tile079	S3	sames as tile076, steep = 0.94
tile080	S4	same as tile076, steep = 0.74
tile081	S5	sames as tile076, likelihood weights all set to 1.0
tile082	S6	same as tile076, 2% increase in catchability for logbook index
tile083	S7	same as tile076, drop the MARMAP index
tile084	S8	same as tile076, drop the commercial logbook index
tile085	S11	same as tile076, two periods of logistic selectivity (2nd period starting in 2005)
tile086		same as tile076, two periods of dome-shaped selectivity (uses spp_make_Robject-02.cxx)
tile087	S14	same as tile076, allow time-varying L50 parameter (1995-2010) with slope fixed to tile076 value
tile088	S9	same as tile085, with 2nd period starting in 2003
tile089	S10	same as tile085, with 2nd period starting in 2004
tile090	S12	same as tile085, with 2nd period starting in 2006
tile091	S13	same as tile085, with 2nd period starting in 2007
tile092	S15	same as tile076, allow random walk in catchability for longline CPUE
tile093	S16	same as tile076, dropping 2004-2006 commercial longline age comp data
tile094		same as tile076, dropping comm handline age comp in 2006
tile095		same as tile076, no ageing error
Tile-retro1	S17	retro1 -same as tile076, minus one year of data
Tile-retro2	S18	retro2 -same as tile076, minus two year of data
Tile-retro3	S19	retro3 - same as tile076, minus three year of data
Tile-retro4	S20	retro4 -same as tile076, minus four year of data
Tile-retro5	S21	retro5 - same as tile076, minus five year of data
Tile-retro6	S22	retro6 - same as tile076, minus six year of data
Tile-retro7	S23	retro7 -same as tile076, minus seven year of data
Tile-retro8	S24	retro8 - same as tile076, minus eight year of data