Development and diagnostics of the Beaufort assessment model applied to black sea bass

Sustainable Fisheries Branch, NMFS Beaufort Lab

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Development and diagnostics of the Beaufort assessment model applied to black sea bass

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1. Introduction

The BAM, a statistical catch-age formulation, was applied to black sea bass as the primary stock assessment model. The model is detailed in SEDAR25-RW03, 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.

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 black sea bass, CVs of landings and discards (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 and discards 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 these initial weights, the BAM was fit to the data. In this model run, the spawner recruit curve was estimated with low steepness (h=0.3) and low recruitment variability (σ_R=0.23), and dynamics observed in the indices of abundance were not well fitted (Figure 1), a symptom related to low σ_R. 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,

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

Here, N_y is the assumed sample size, and $P_{obs,iy}$ is the observed proportion of fish in the ith 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.

Not all data sources had enough years of data to compute meaningful SDNRs. In these cases, weights were borrowed from similar data sources for which weights could be computed. For example, only a single year of age composition data from the MARMAP blackfish/snapper traps was available, and so the weight was borrowed from MARMAP chevron traps.

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 small 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 headboat 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). Furthermore, the recruitment variability was estimated at its lower bound (σ_R=0.1). This model run was considered a sensitivity run in the assessment (Sensitivity Run S6 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 indices to better match the observed annual variation. In many cases, such annual variation may simply be observation error, but the indices in this assessment were strongly correlated, as were first-differences of indices (section 2 of the AW report). Thus, the AW panel thought that the indices were likely tracking signals of abundance and should be more closely fit.

The AW considered index weights in the range of [1.0, 4.0] for the four indices that were most strongly correlated (the headboat discard index was not up-weighted). This range of weights improved the ability of the model to track annual variation in indices, as revealed by visual inspection of fits and residual patterns, and quantified by mean square errors (Figure 3). These improvements in fits to indices came with some tradeoff in fits to composition data, particularly age composition data (Figure 3). The AW chose a base-level weight of 2.5 for indices, which appeared to provide a reasonable compromise between fitting the indices well and erosion in fitting composition data. Uncertainty analysis included index weighting to examine its influence on results.

3. Model diagnostics

3.1. *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 4). 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).

3.2. *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 as,

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

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 5). For example, strong year classes of black sea bass were predicted in 1994 and 2001 (Figure 5, 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 (Figure 3).

3.3. *Likelihood profiles*

Likelihood profiles were computed for several key parameters including steepness, R0, and natural mortality. For the profile on steepness, the prior distribution applied in the base run was not used. Each of these three profiles showed a reasonably well defined minimum (Figure 6; Tables 2–4). However, the scale of the responses (y-axis) was not large, indicating that the data provided only weak information on these parameters. The minimum for steepness was slightly lower (h=0.40) than the estimate from the base run (h=0.49), indicating that the prior distribution affected the estimate some. The profile on natural mortality had a minimum quite close to the point estimate recommended by the DW (M=0.38).

3.4. *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 sampling distributions of those parameters are shown in Figure 7. The bootstrap procedure on landings, discards, indices, age compositions, and length compositions is also described in the assessment report (bootstrapped data sets not shown).

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 8).

3.5 *Catch curve analysis*

Catch curves were examined as a simple diagnostic for comparing the general range of estimated total mortality rates (Z) to that from the BAM. Their analysis also contributed to discussions on selectivity, in the sense that comparing estimates of Z across fleets can shed light on relative shapes of selectivity (e.g., dome-shaped selectivity should provide higher estimates of Z than would flat-topped).

Perhaps the strongest assumption behind these methods is that the population is in steady state, i.e., that the age structure is stable through time as a consequence of constant recruitment and constant mortality. Both methods also assume that ageing error is negligible and that fish older than some known age are equally vulnerable to sampling. The strong assumptions of catch curve analysis are never met by real fish populations, which is one reason why, when other assessment methods are available, catch curve analysis is used as a diagnostic.

In this analysis, catch curves were represented by synthetic cohorts (i.e., proportions at age within years) and were analyzed using the Chapman-Robson estimator (Chapman and Robson 1960; Robson and Chapman 1961) and the linear regression estimator (Quinn and Deriso 1999) of the log-transformed proportions at age. Performance of the two methods will vary across data sets, but the Chapman−Robson estimator has been found in some cases to be more robust to violations of assumptions (Murphy 1997; Dunn et al. 2002).

Data were analyzed from the commercial fleets (Figure 9) and from the headboat fleet and MARMAP survey (Figure 10). Estimates of Z generally ranged between 1.0 and 1.5. This range was consistent with estimates of total mortality from the BAM. Furthermore, the various catch-curve estimates were on the same general scale (although with much variability), and were thus consistent with the fleets/surveys examined here all having similar patterns of selectivity for black sea bass.

4. Literature cited

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Table 1. SDNRs and weights computed in model fits. The component weights from the final iteration are shaded. Fleets/surveys represented are MARMAP blackfish/snapper traps (Mbft), MARMAP chevron traps (Mcvt), headboat, MRIP (i.e., general recreational), commercial lines and commercial pots. L represents landings, and D represents discards.

		SDNR							Weights							Cumulative weights (for next iteration)						
		MARMAP		Headboat		MRIP	Comm. L		MARMAP		Headboat		MRIP	Comm. L		MARMAP		Headboat		MRIP	Comm. L	
Run	**Source**	**Mbft**	**Mcvt**	**L**	**D**	**L**	**lines**	**pots**	**Mbft**	**Mcvt**	**L**	**D**	**L**	**lines**	**pots**	**Mbft**	**Mcvt**	**L**	**D**	**L**	**lines**	**pots**
1	CPUE	2.63	3.19	1.93	2.41	-	1.46	-	0.38	0.31	0.52	0.41	-	0.68	-	0.38	0.31	0.52	0.41	-	0.68	-
	Length comp	1.95	-	4.32	2.19	5.24	1.67	-	0.26	-	0.05	0.21	0.04	0.36	-	0.26	-	0.05	0.21	0.04	0.36	-
	Age comp	-	3.38	3.63	-	2.35	1.30	2.60	-	0.09	0.08	-	0.18	0.59	0.15	-	0.09	0.08	-	0.18	0.59	0.15
2	CPUE	0.80	1.00	0.86	1.06	-	0.87	-	1.25	1.00	1.16	0.94	-	1.15	-	0.48	0.31	0.60	0.39	-	0.79	-
	Length comp	0.95	-	1.12	1.11	1.26	1.06	-	1.11	-	0.80	0.81	0.63	0.89	-	0.29	-	0.04	0.17	0.02	0.32	-
	Age comp	-	0.73	0.82	-	0.66	0.95	1.05	-	1.88	1.49	-	2.30	1.11	0.91	-	0.16	0.11	-	0.42	0.66	0.13
3	CPUE	0.97	0.99	0.90	1.01	-	0.95	-	1.03	1.01	1.11	0.99	-	1.05	-	0.49	0.32	0.67	0.39	-	0.83	-
	Length comp	1.06	-	1.04	0.99	0.99	1.07	-	0.89	-	0.92	1.02	1.02	0.87	-	0.26	-	0.04	0.17	0.02	0.28	-
	Age comp	-	0.89	0.82	-	0.75	0.96	0.96	-	1.26	1.49	-	1.78	1.09	1.09	-	0.21	0.17	-	0.74	0.71	0.15
4	CPUE	1.00	1.02	0.96	1.02	-	0.99	-	1.00	0.98	1.04	0.98	-	1.01	-	0.49	0.31	0.70	0.38	-	0.84	-
	Length comp	1.09	-	1.08	0.98	1.03	0.99	-	0.84	-	0.86	1.04	0.94	1.02	-	0.22	-	0.03	0.18	0.02	0.28	-
	Age comp	-	0.99	0.99	-	0.89	0.99	1.01	-	1.02	1.02	-	1.26	1.02	0.98	-	0.21	0.17	-	0.93	0.73	0.14
5	CPUE	0.99	0.99	0.97	1.00	-	1.00	-														
	Length comp	1.06	-	0.99	0.99	1.06	1.05	-														
	Age comp	-	0.98	0.97	-	0.96	1.00	0.98														

Table 2. Likelihood profile over steepness (h). nLL indicates negative log-likelihood, U indicates indices, len indicates length compositions, and age indicates age compositions. Additional descriptors are SR=spawner recruit function, Mbft=MARMAP blackfish/snapper traps, Mcvt=MARMAP chevron traps, cl=commercial lines, cp=commercial pots, hb=headboat, hbd=headboat discards, and mrip=general recreational.

h	nLL (data)	nLL (penalized)	nLL (SR)	U. Mbft	U. Mcvt	U.cl	U.hb	U. hbd	len. Mbft	len. cl	len. cp	len. hb	len. mrip	len. hb.D	age. Mbft	age. Mcvt	age. cl	age. cp	age. hb	age. mrip
0.25	704.8	730.1	5.2	2.0	190.4	60.3	77.6	4.2	17.5	21.2	0.9	47.8	87.6	15.1	3.7	97.1	31.2	2.8	24.6	13.2
0.30	699.8	705.0	-15.4	2.7	194.5	58.8	79.1	3.3	18.4	21.5	2.3	45.1	89.8	15.6	2.1	86.2	28.7	5.9	24.5	12.9
0.35	699.8	703.7	-16.8	2.7	194.7	58.7	79.0	3.3	18.4	21.6	2.4	45.2	89.9	15.6	2.1	85.8	28.6	6.1	24.5	12.8
0.40	699.7	703.4	-16.9	2.6	194.6	58.7	79.0	3.2	18.3	21.6	2.4	45.3	90.0	15.7	2.1	85.7	28.6	6.2	24.5	12.8
0.45	699.5	703.7	-16.4	2.5	194.3	58.7	79.0	3.2	18.2	21.6	2.4	45.4	90.0	15.7	2.1	85.8	28.6	6.2	24.6	12.8
0.50	699.4	704.1	-15.8	2.4	194.0	58.8	79.0	3.2	18.1	21.6	2.5	45.5	90.0	15.7	2.2	86.0	28.7	6.2	24.6	12.8
0.55	699.3	704.5	-15.2	2.3	193.8	58.8	79.0	3.2	18.0	21.6	2.5	45.5	90.0	15.7	2.2	86.2	28.7	6.2	24.5	12.8
0.60	699.2	705.0	-14.5	2.2	193.5	58.8	79.1	3.2	18.0	21.6	2.5	45.6	90.0	15.7	2.2	86.3	28.8	6.2	24.5	12.8
0.65	699.1	705.4	-14.0	2.2	193.3	58.8	79.1	3.2	17.9	21.6	2.5	45.6	90.0	15.7	2.2	86.5	28.8	6.2	24.5	12.8
0.70	699.0	705.8	-13.4	2.1	193.2	58.8	79.1	3.2	17.9	21.6	2.4	45.6	90.0	15.7	2.2	86.6	28.9	6.2	24.5	12.8
0.75	699.0	706.2	-13.0	2.1	193.0	58.8	79.1	3.2	17.8	21.6	2.4	45.7	90.0	15.7	2.2	86.7	28.9	6.2	24.5	12.8
0.80	698.9	706.5	-12.5	2.1	192.9	58.8	79.1	3.2	17.8	21.7	2.4	45.7	90.0	15.7	2.2	86.8	28.9	6.1	24.5	12.8
0.85	698.9	706.9	-12.1	2.1	192.8	58.8	79.1	3.2	17.8	21.7	2.4	45.7	89.9	15.7	2.2	86.9	29.0	6.1	24.5	12.8
0.90	698.8	707.1	-11.8	2.0	192.7	58.9	79.1	3.2	17.8	21.7	2.4	45.7	89.9	15.7	2.2	87.0	29.0	6.1	24.5	12.8
0.95	698.8	707.4	-11.5	2.0	192.6	58.9	79.2	3.2	17.7	21.7	2.4	45.8	89.9	15.7	2.2	87.0	29.0	6.1	24.5	12.8

Table 3. Likelihood profile over R0. nLL indicates negative log-likelihood, U indicates indices, len indicates length compositions, and age indicates age compositions. Additional descriptors are SR=spawner recruit function, Mbft=MARMAP blackfish/snapper traps, Mcvt=MARMAP chevron traps, cl=commercial lines, cp=commercial pots, hb=headboat, hbd=headboat discards, and mrip=general recreational.

R0	nLL (data)	nLL (penalized)	nLL (SR)	U. Mbft	U. Mcvt	U.cl	U.hb	U. hbd	len. Mbft	len. cl	len. cp	len. hb	len. mrip	len. hb.D	age. Mbft	age. Mcvt	age. cl	age. cp	age. hb	age. mrip
1.00E+07	920.4	1017.4	34.6	40.5	198.8	62.0	88.4	5.0	22.8	21.3	3.8	65.0	85.9	15.8	108.8	117.9	31.9	5.3	26.5	12.0
1.50E+07	778.9	847.9	36.3	2.2	176.0	59.2	75.3	5.4	22.3	23.8	0.8	65.8	89.7	14.8	24.4	137.3	32.1	4.0	24.1	12.9
2.00E+07	723.2	768.3	23.6	1.0	171.7	60.2	75.9	5.8	16.3	23.6	1.4	53.5	92.9	14.5	7.5	111.6	31.7	7.5	25.7	12.9
2.50E+07	700.9	722.3	2.4	1.1	183.9	59.5	77.2	4.4	16.0	22.6	1.9	48.3	91.5	14.7	2.9	94.3	29.8	6.8	24.9	12.9
3.00E+07	698.8	705.4	-12.6	2.0	192.5	58.9	78.9	3.2	17.8	21.7	2.4	45.8	90.0	15.6	2.2	87.0	28.9	6.2	24.5	12.8
3.50E+07	699.3	704.6	-15.3	2.3	193.8	58.8	79.0	3.2	18.0	21.6	2.4	45.5	90.0	15.7	2.2	86.2	28.7	6.2	24.5	12.8
4.00E+07	699.6	704.6	-16.4	2.5	194.3	58.7	79.0	3.2	18.2	21.6	2.5	45.4	90.0	15.7	2.1	85.8	28.6	6.2	24.6	12.8
4.50E+07	699.7	704.8	-16.9	2.6	194.6	58.7	79.0	3.2	18.3	21.6	2.5	45.3	90.0	15.7	2.1	85.6	28.6	6.2	24.6	12.8
5.00E+07	699.8	705.1	-17.0	2.6	194.7	58.7	79.1	3.2	18.3	21.6	2.5	45.2	90.0	15.7	2.1	85.6	28.5	6.3	24.6	12.8
5.50E+07	699.9	705.3	-17.1	2.6	194.7	58.7	79.1	3.2	18.4	21.6	2.5	45.2	90.0	15.7	2.1	85.5	28.5	6.3	24.6	12.8
6.00E+07	699.9	705.6	-17.0	2.7	194.8	58.7	79.1	3.2	18.4	21.6	2.5	45.2	90.0	15.7	2.1	85.5	28.5	6.3	24.6	12.8
6.50E+07	699.9	705.8	-16.9	2.7	194.8	58.7	79.1	3.2	18.4	21.6	2.5	45.2	90.0	15.7	2.1	85.5	28.5	6.3	24.5	12.8
7.00E+07	700.0	706.0	-16.8	2.7	194.8	58.7	79.1	3.2	18.4	21.6	2.5	45.1	90.0	15.7	2.1	85.6	28.5	6.3	24.5	12.8

Table 4. Likelihood profile over natural mortality (M). In each case, age dependent Lorenzen natural mortality was scaled to M, as in the base run. nLL indicates negative log-likelihood, U indicates indices, len indicates length compositions, and age indicates age compositions. Additional descriptors are SR=spawner recruit function, Mbft=MARMAP blackfish/snapper traps, Mcvt=MARMAP chevron traps, cl=commercial lines, cp=commercial pots, hb=headboat, hbd=headboat discards, and mrip=general recreational.

M	nLL (data)	nLL (penalized)	nLL (SR)	U. Mbft	U. Mcvt	U.cl	U.hb	U. hbd	len. Mbft	len. cl	len. cp	len. hb	len. mrip	len. hb.D	age. Mbft	age. Mcvt	age. cl	age. cp	age. hb	age. mrip
0.300	699.8	704.6	-15.5	2.6	195.1	56.5	78.2	3.2	18.9	22.1	2.6	46.5	90.4	15.9	2.3	85.3	27.4	6.8	23.7	12.6
0.325	699.6	704.5	-15.7	2.6	194.9	57.2	78.4	3.2	18.7	21.9	2.6	46.2	90.3	15.9	2.3	85.4	27.7	6.7	24.0	12.6
0.350	699.5	704.4	-15.8	2.5	194.6	57.9	78.7	3.2	18.4	21.8	2.5	45.8	90.2	15.8	2.2	85.6	28.1	6.5	24.2	12.7
0.375	699.4	704.5	-15.9	2.4	194.2	58.6	78.9	3.2	18.2	21.6	2.5	45.5	90.0	15.7	2.2	85.9	28.6	6.3	24.5	12.8
0.400	699.4	704.6	-16.0	2.3	193.8	59.3	79.2	3.2	18.0	21.5	2.4	45.2	89.9	15.7	2.1	86.1	29.0	6.0	24.8	12.9
0.425	699.5	704.9	-16.1	2.3	193.4	60.1	79.5	3.2	17.7	21.4	2.4	44.9	89.8	15.6	2.1	86.4	29.4	5.8	25.0	13.0
0.450	699.6	705.2	-16.1	2.2	192.9	60.9	79.8	3.2	17.5	21.3	2.3	44.6	89.6	15.5	2.0	86.7	29.9	5.6	25.3	13.1
0.475	699.7	705.5	-16.2	2.1	192.3	61.7	80.2	3.2	17.3	21.2	2.2	44.3	89.5	15.5	2.0	87.0	30.4	5.4	25.6	13.2
0.500	699.9	705.9	-16.3	2.0	191.7	62.5	80.5	3.2	17.1	21.1	2.2	44.0	89.4	15.4	2.0	87.3	30.9	5.2	25.8	13.3

Figure 1. Estimated spawner-recruit curve and three indices (cl=commercial lines, hb=headboat, and Mcvt=MARMAP chevron traps) from model run without iterative re-weighting.

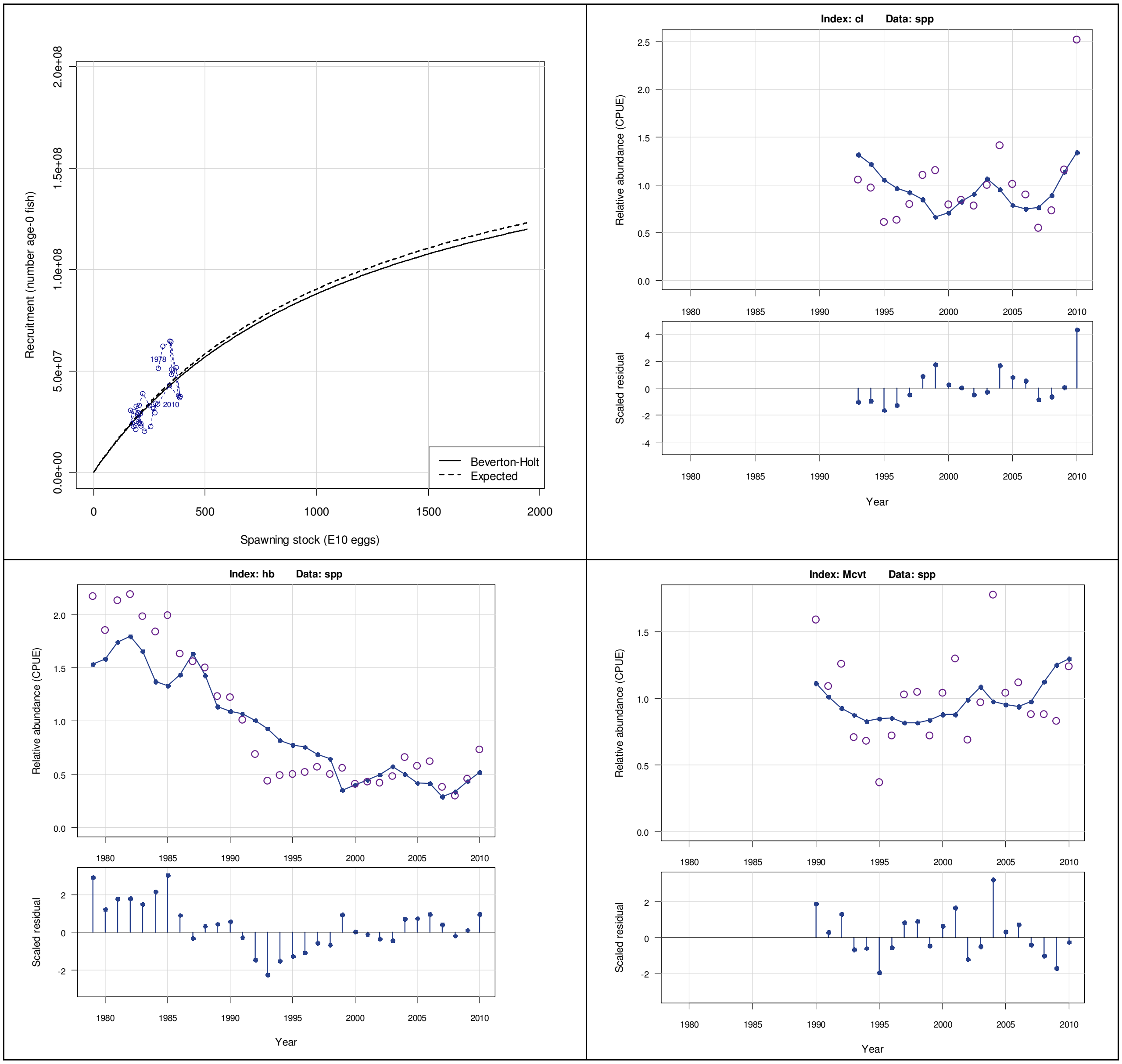


Figure 2. Estimated spawner-recruit curve and three indices (cl=commercial lines, hb=headboat, and Mcvt=MARMAP chevron traps) from model run with all indices and composition data iteratively re-weighted. Weights shown in Table 1.

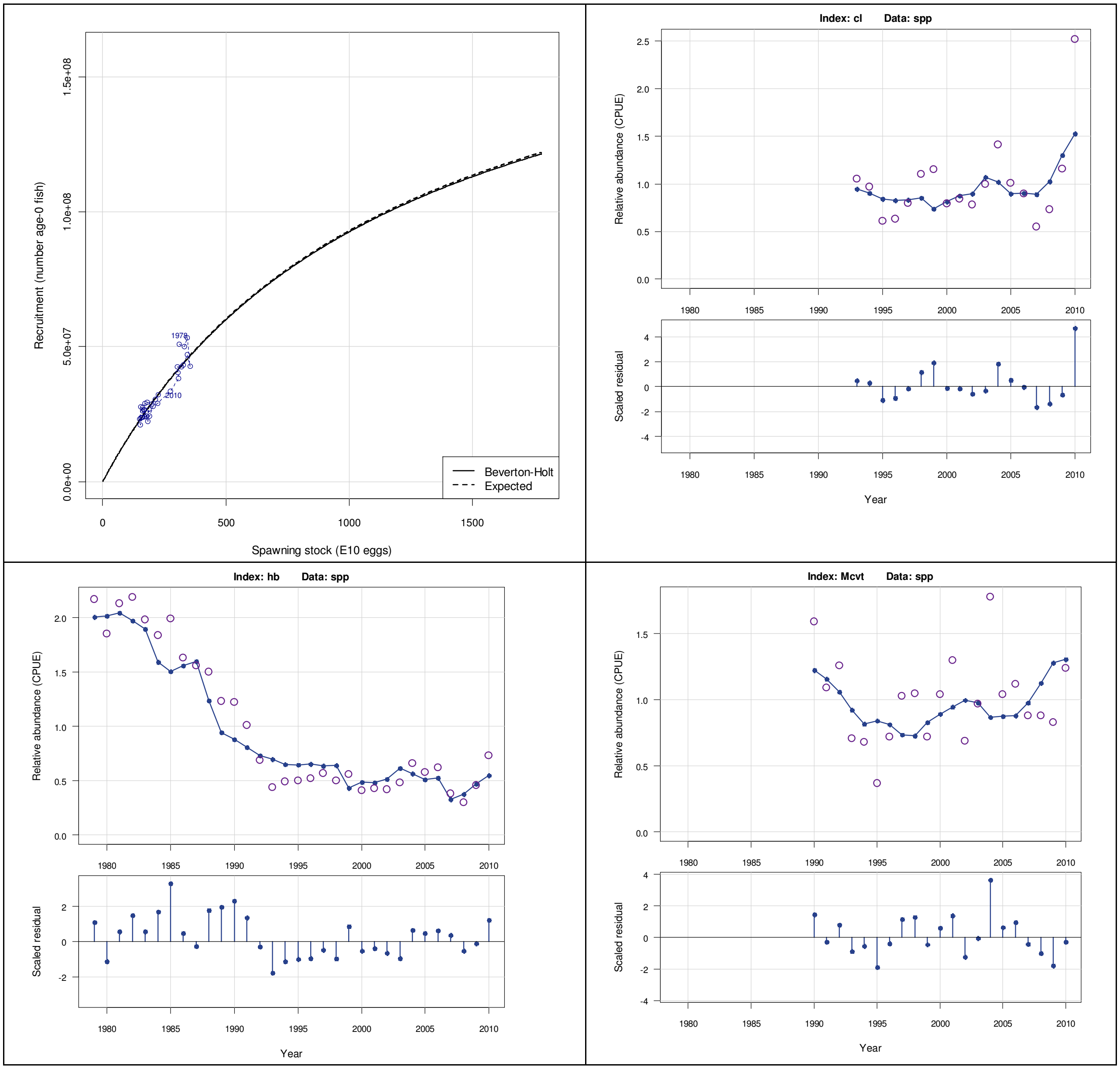


Figure 3. Effect of increased weight on indices. Top panel: Mean square error in fit to indices (Mbft=MARMAP blackfish/snapper traps, Mcvt=MARMAP chevron traps, HB=headboat, comm L=commercial lines). Bottom panel: Negative log likelihood (scaled to minimum) of length and age composition fits. The value of 2.5 was chosen for the base run.

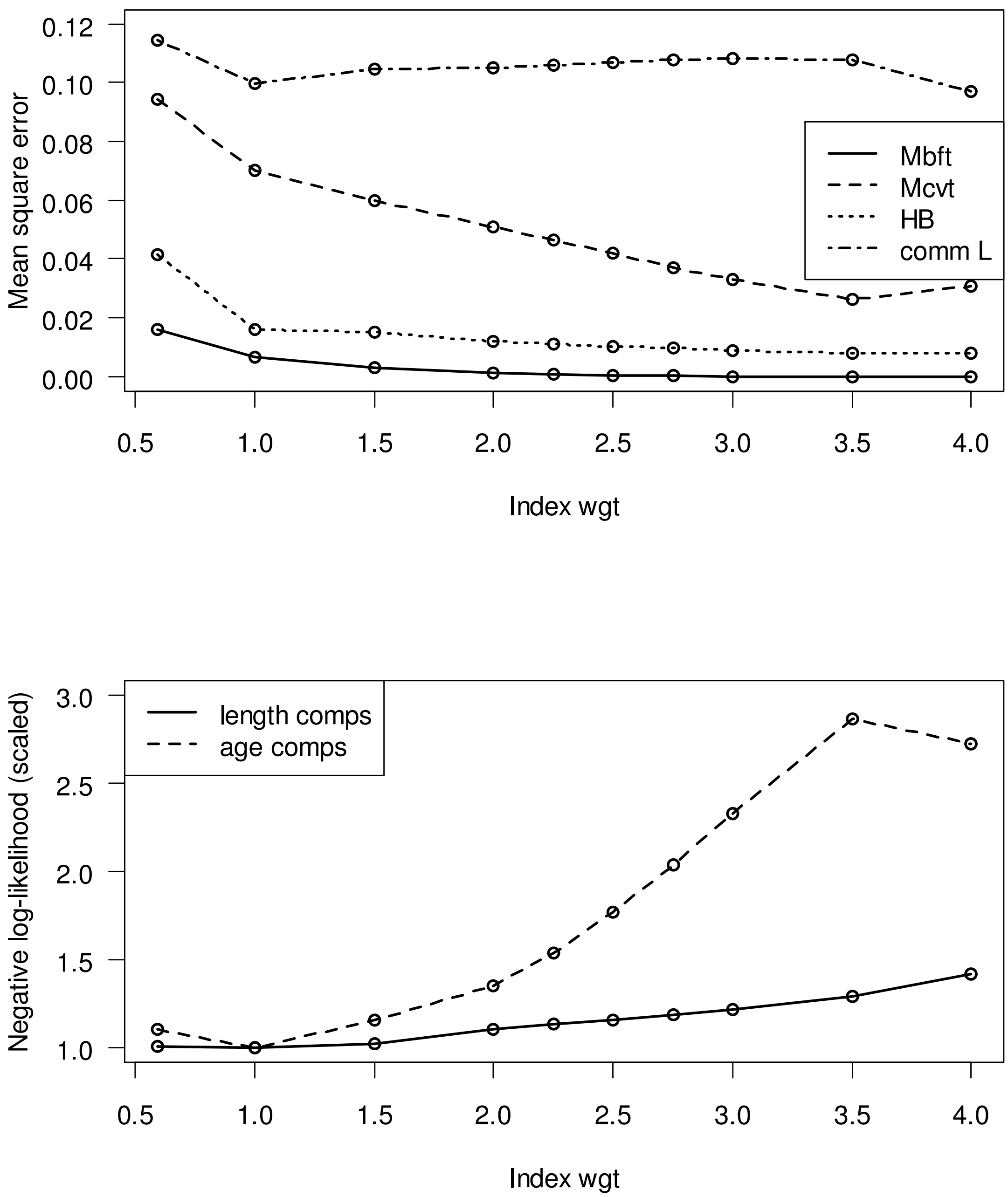


Figure 4. Top panel: bubble plots of length or age composition residuals by fleet or survey; blue (dark) represents overestimates and pink (light) represents underestimates. The size of bubbles within each data set is scaled to the largest residual. Bottom panel: angle (in degrees) between vectors of 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, Mbft=MARMAP blackfish/snapper traps, Mcvt=MARMAP chevron traps, cl=commercial lines, cp=commercial pots, hb=headboat, mrip=general recreational, hb.D=headboat discards.

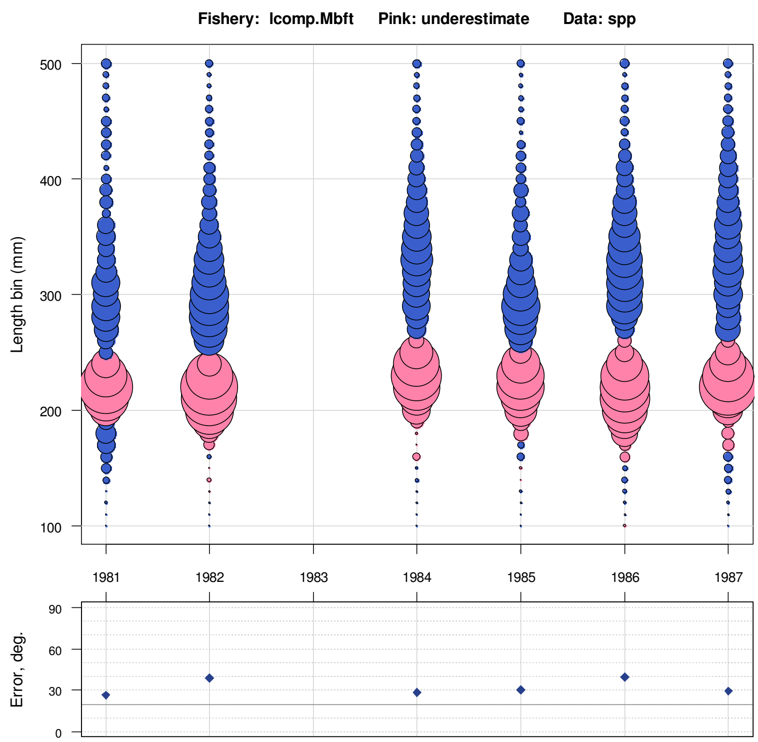
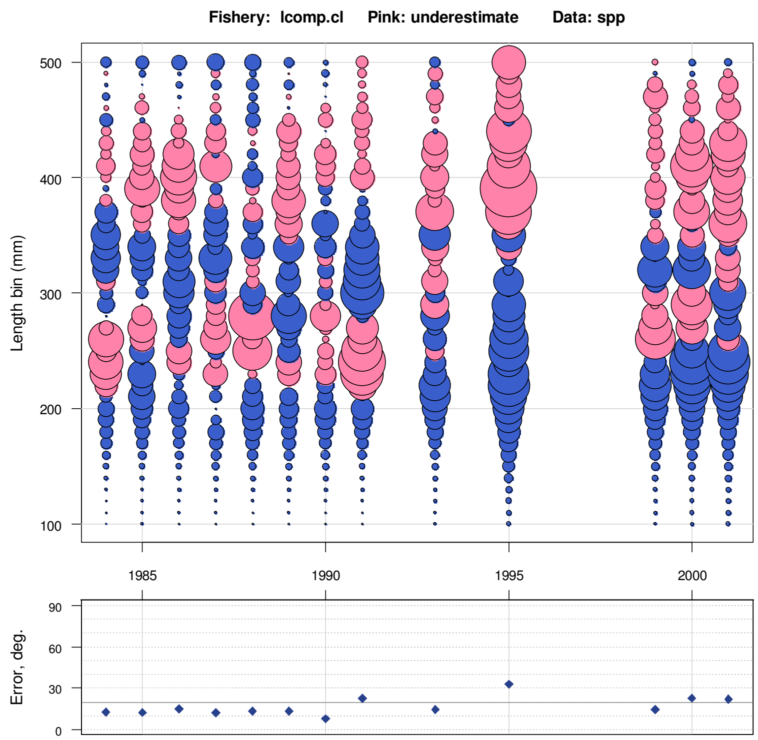


Figure 4 (cont.)



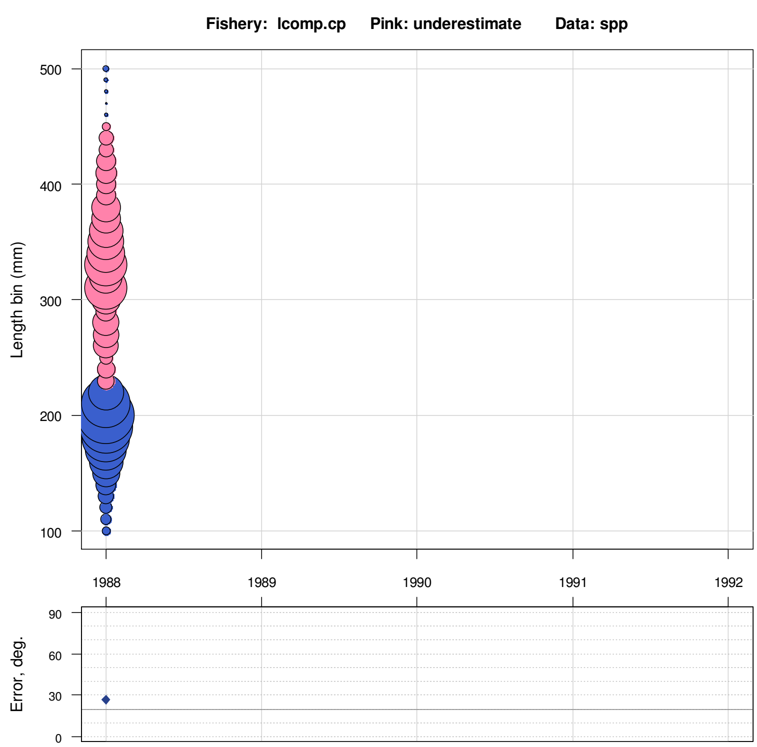
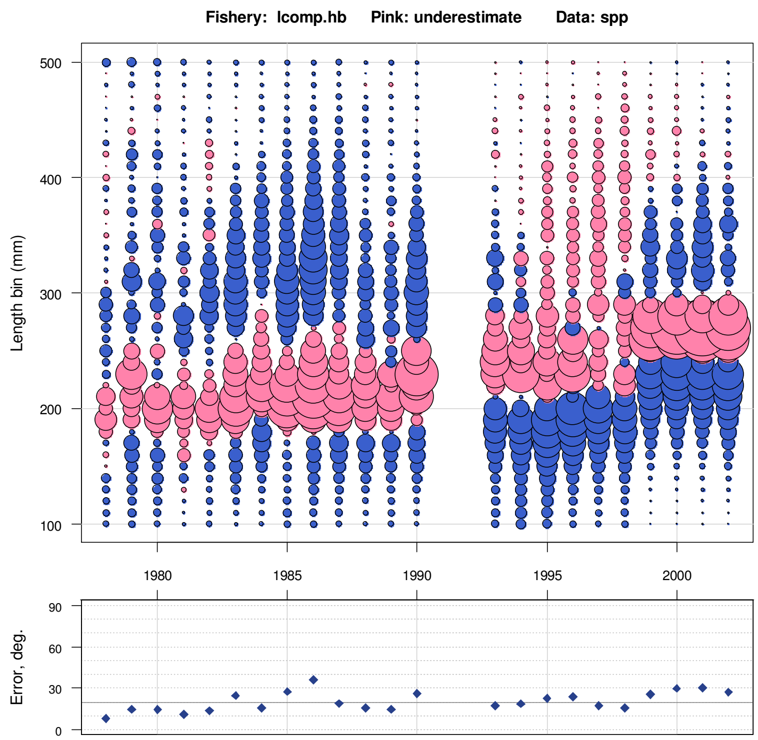
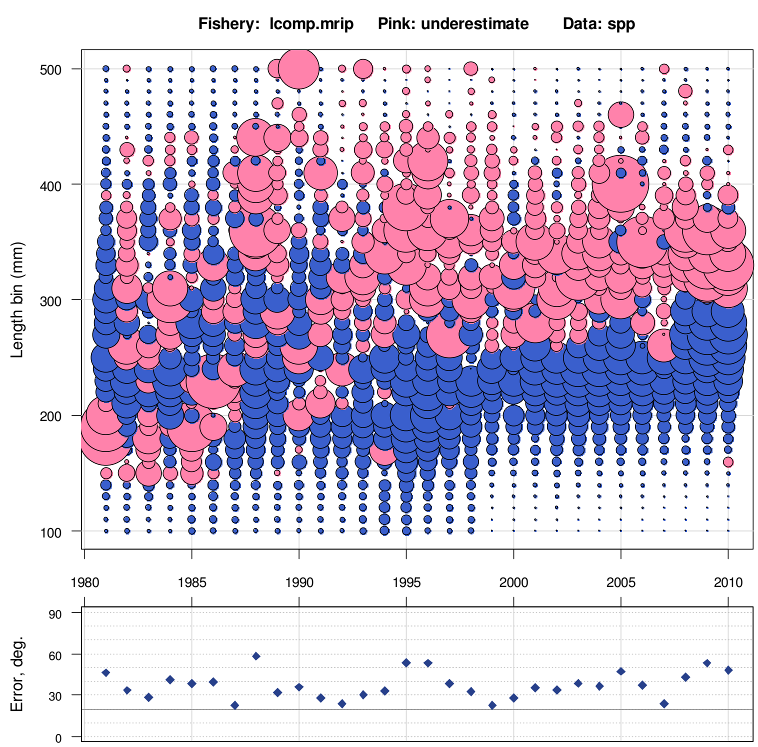


Figure 4 (cont.)





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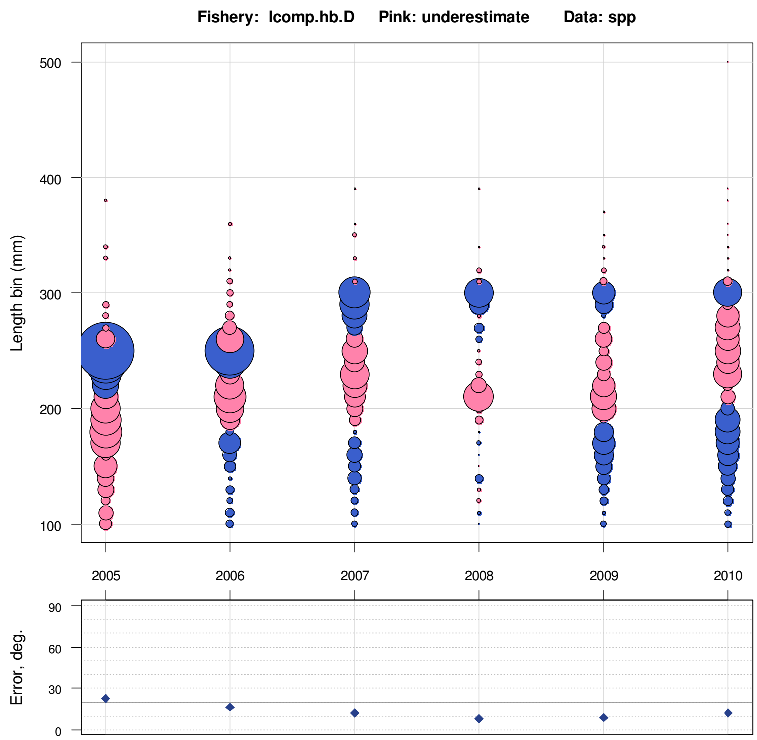


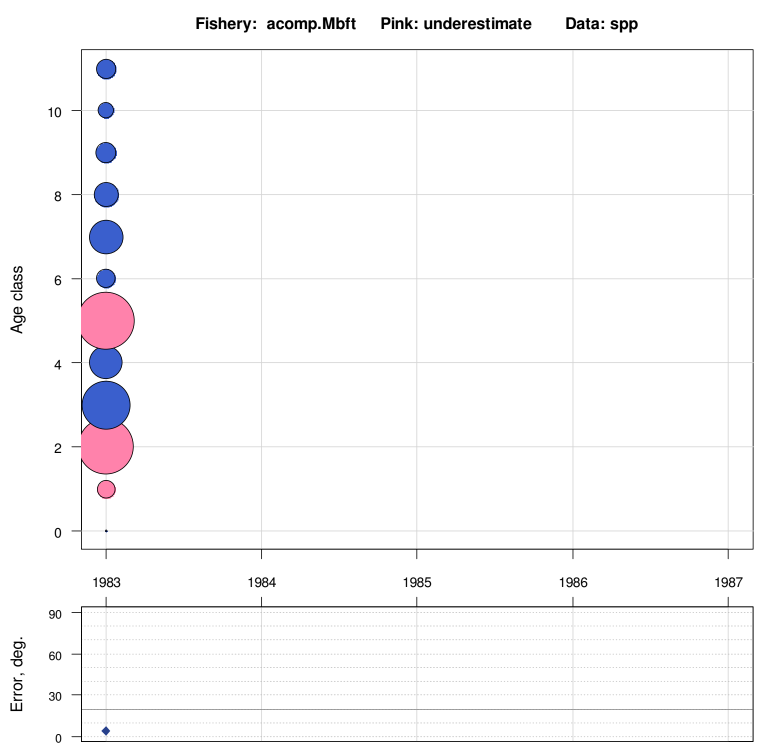
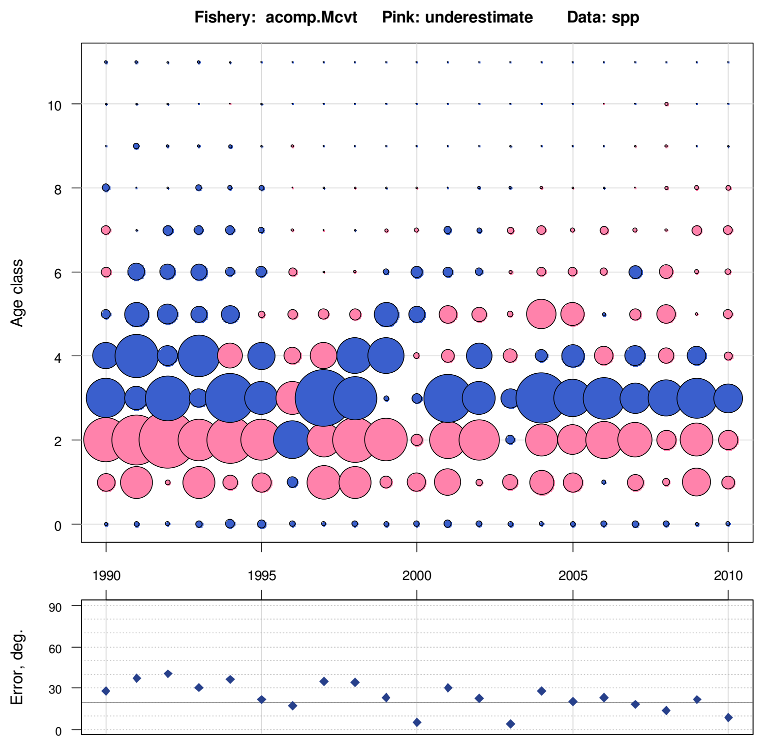


Figure 4 (cont.)



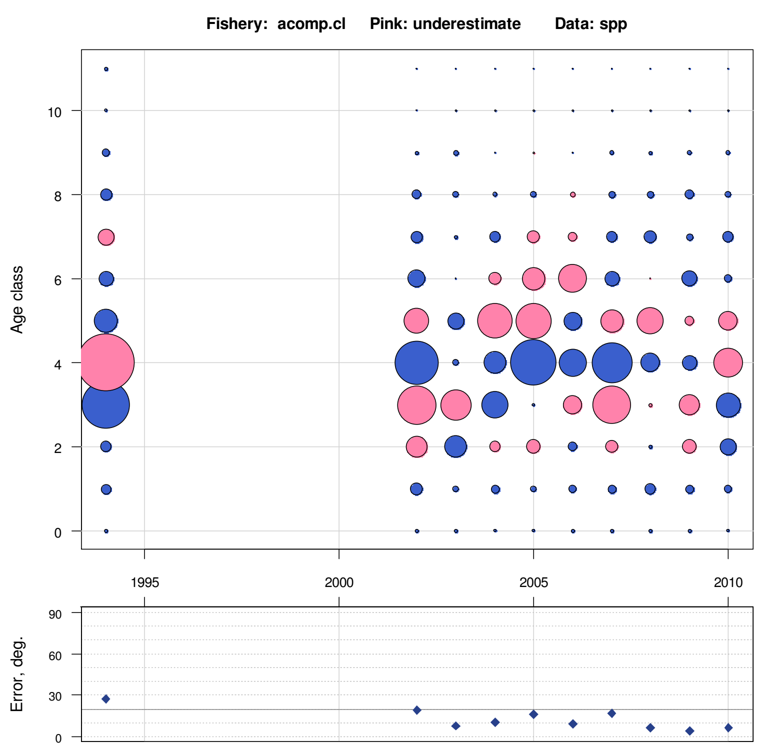
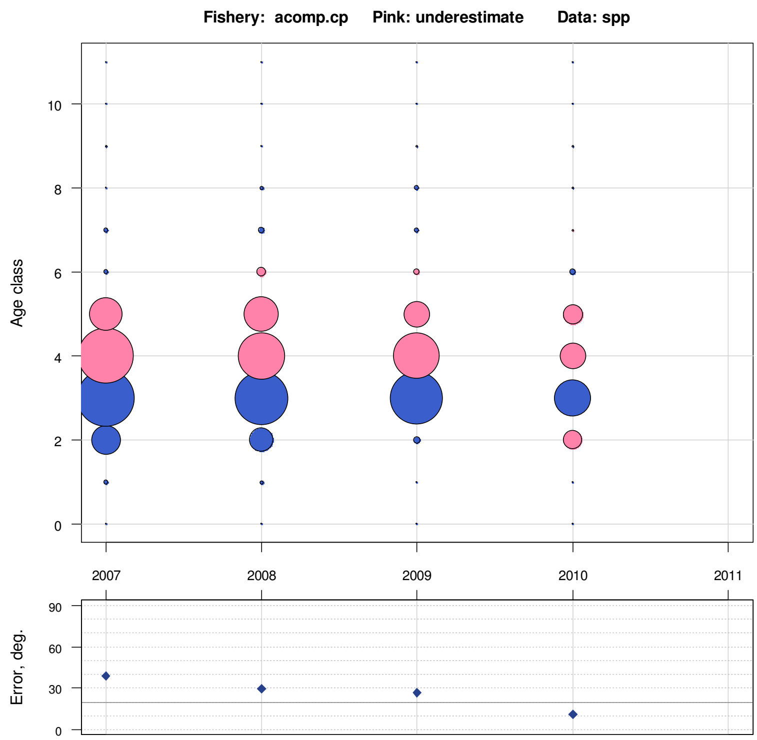


Figure 4 (cont.)



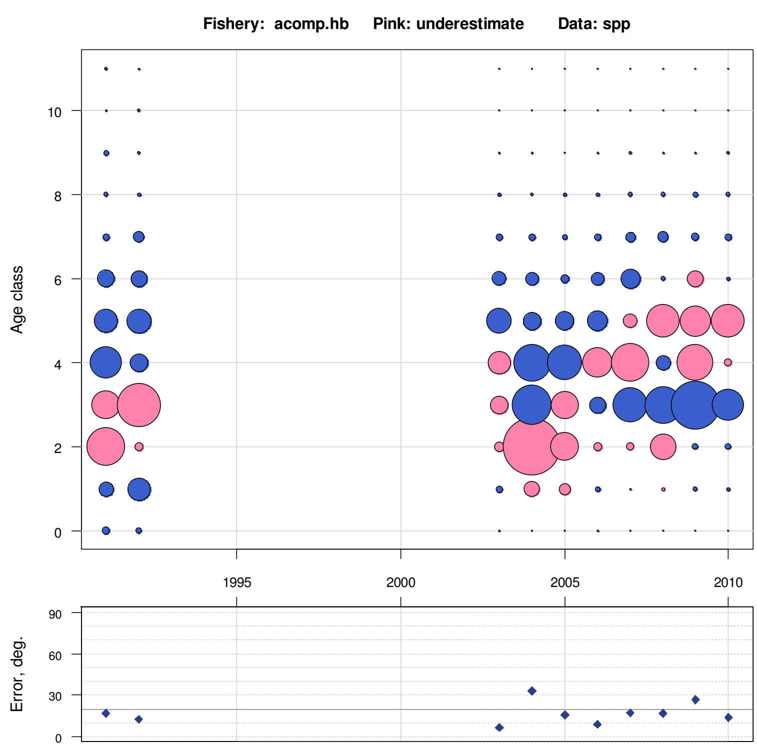


Figure 4 (cont.)

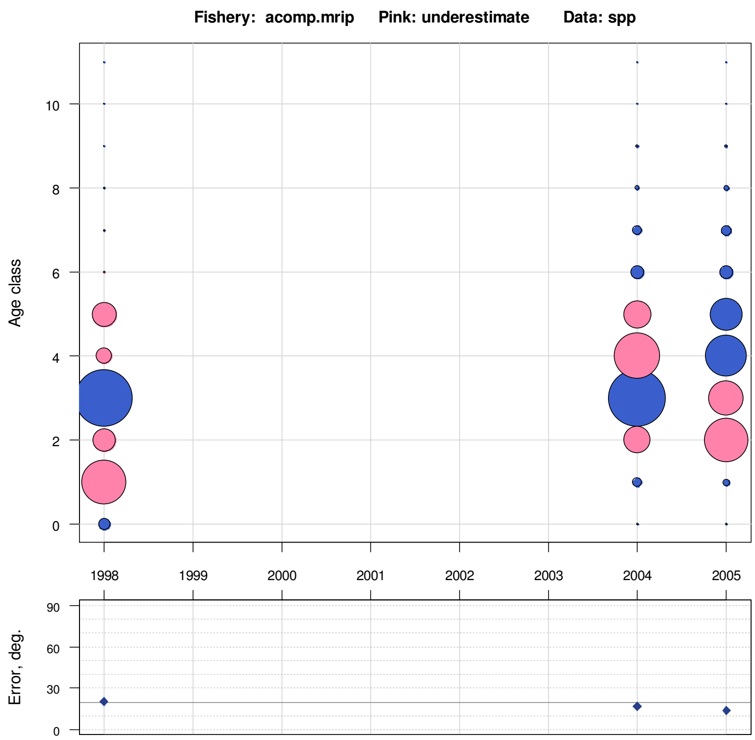


Figure 5. Standardized proportions at year (SPAY) plots. Light gray indicates above average proportion at age, black indicates below average proportion at age. The size of bubbles within each data set is scaled to the largest values. As indicated above the panels, spay plots are shown for predicted abundance, as well as for observed and predicted catches from fleets with suitably long time series of catch at age.

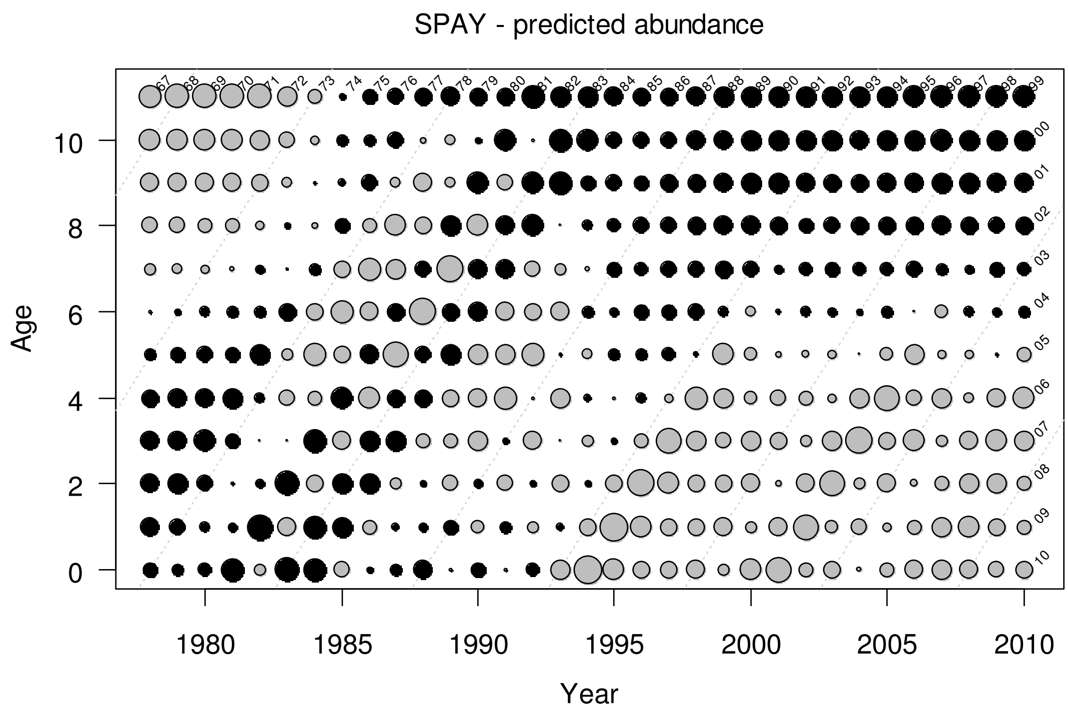
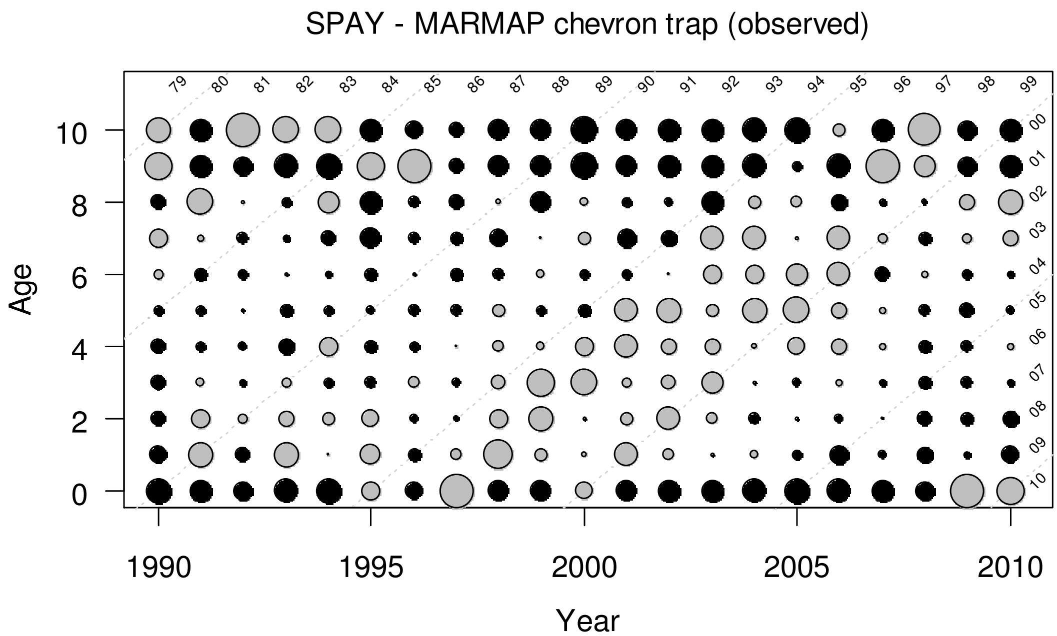


Figure 5 (cont.)



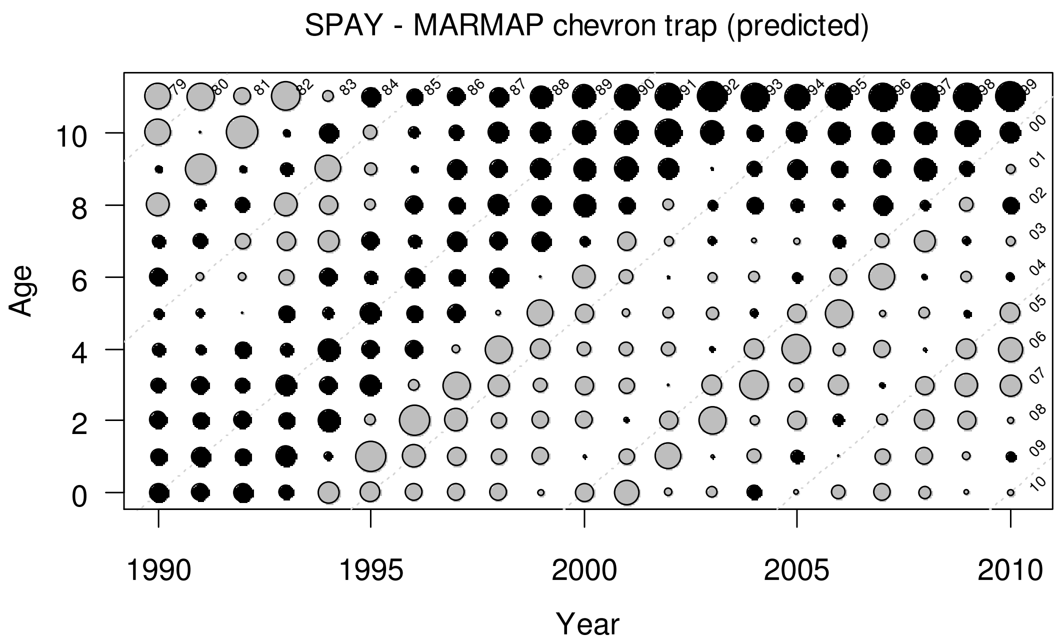
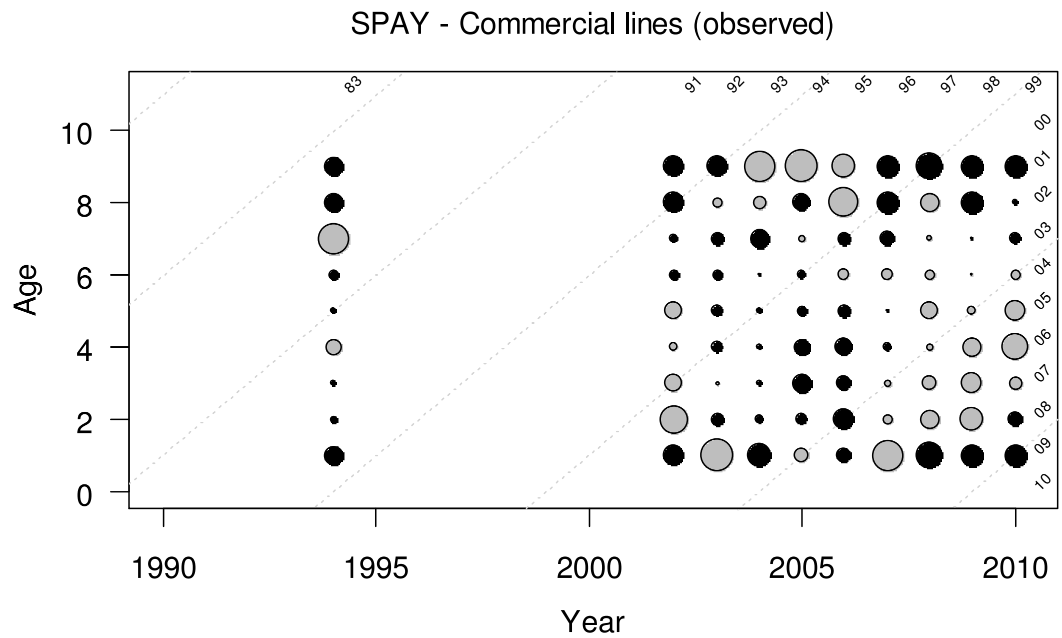


Figure 5 (cont.)



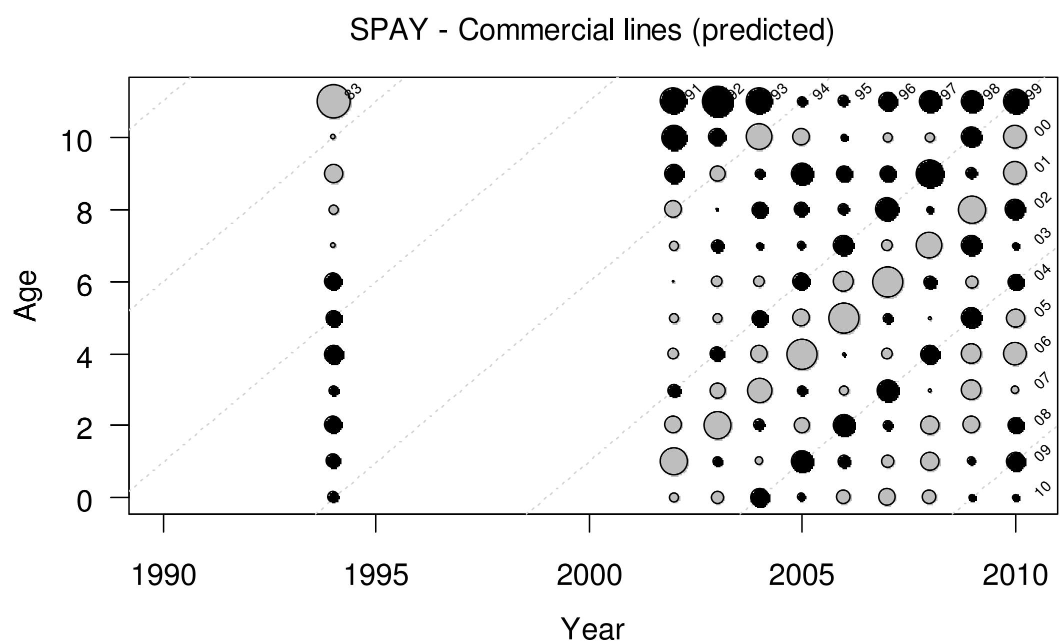
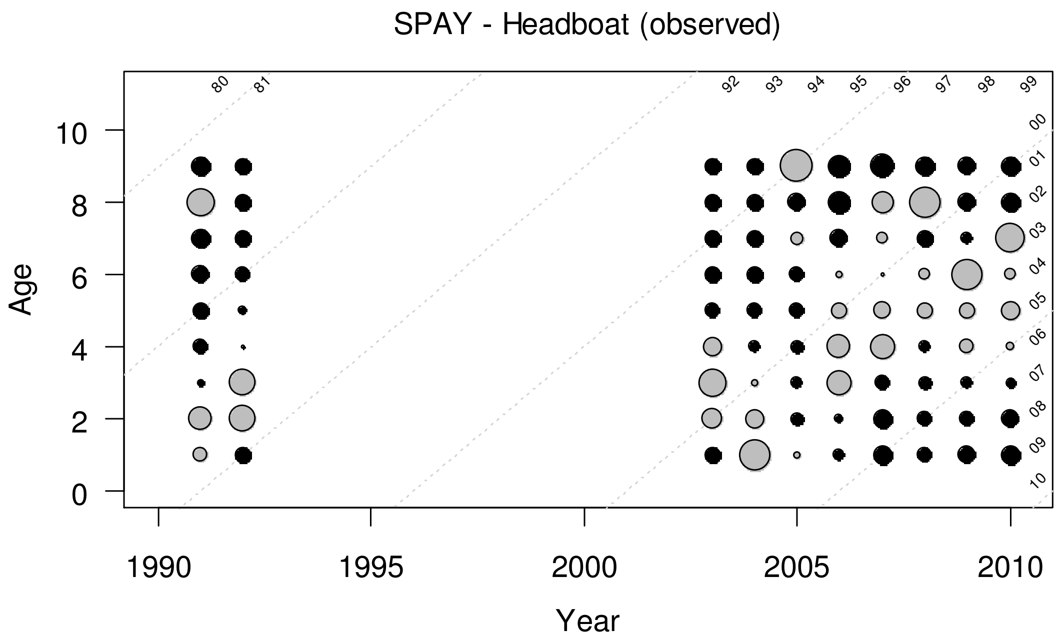


Figure 5 (cont.)



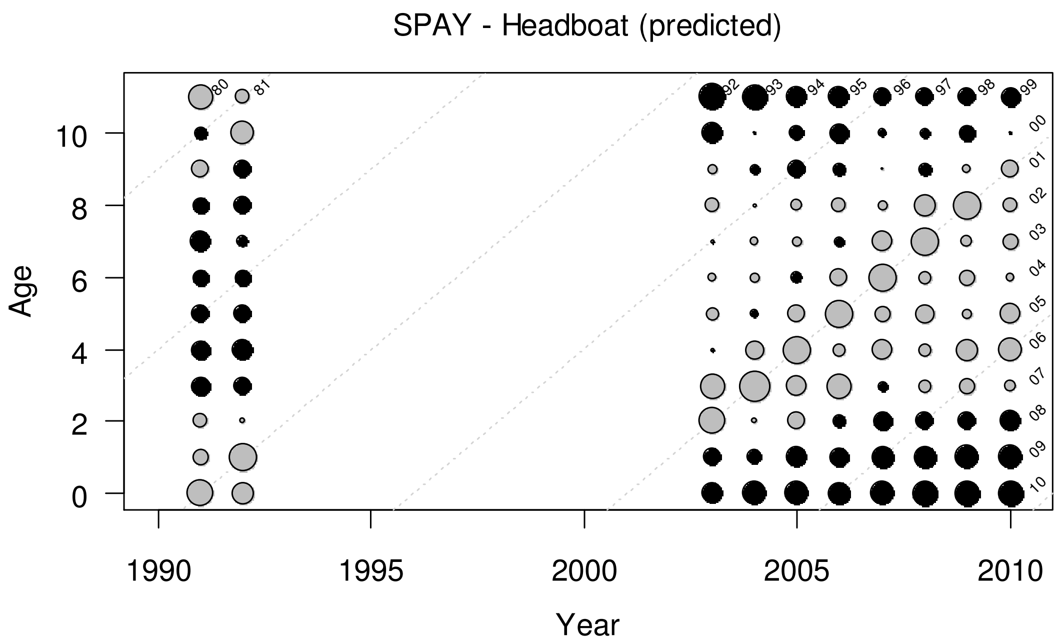
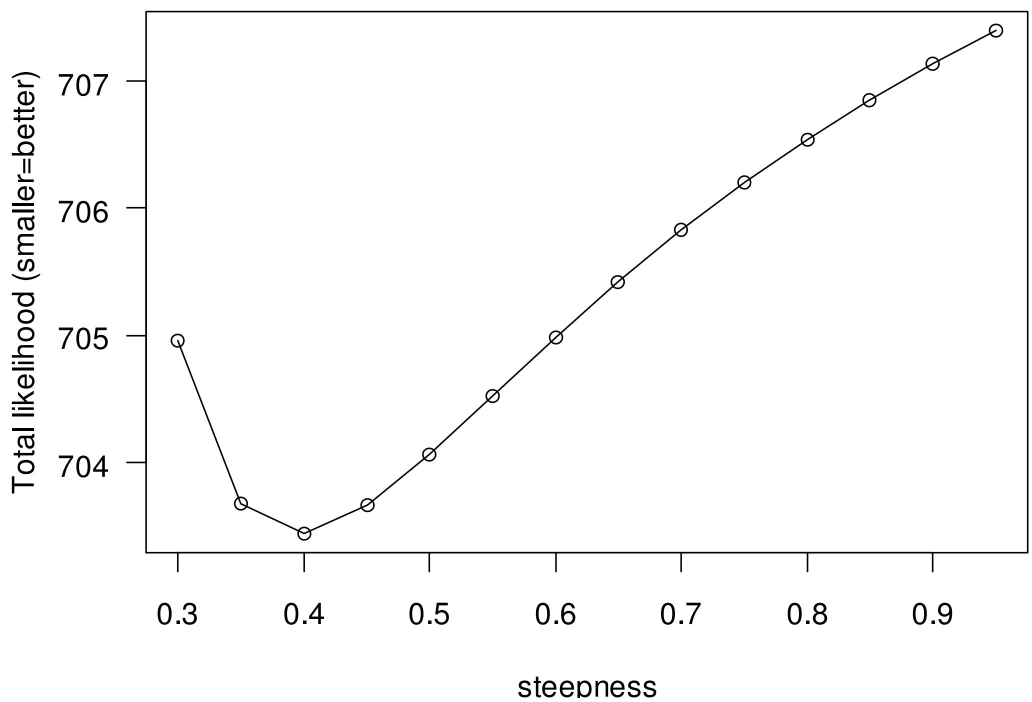


Figure 6. Likelihood profiles on steepness, R0, and natural mortality. For the profile on steepness, the prior distribution applied in the base run was turned off.



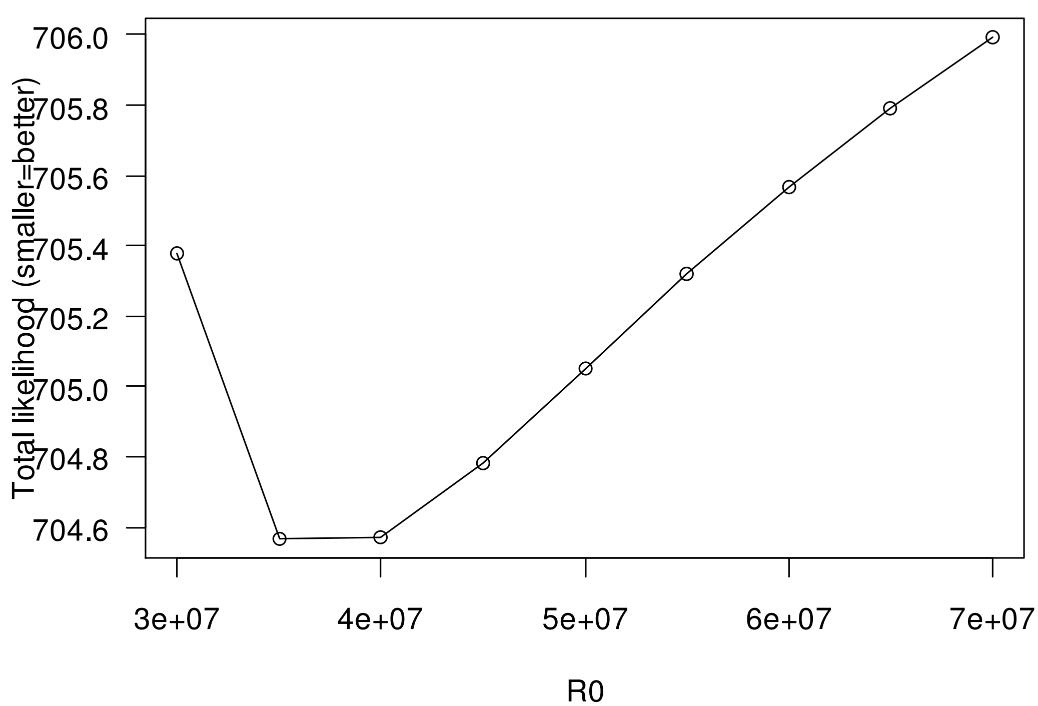


Figure 6 (cont.)

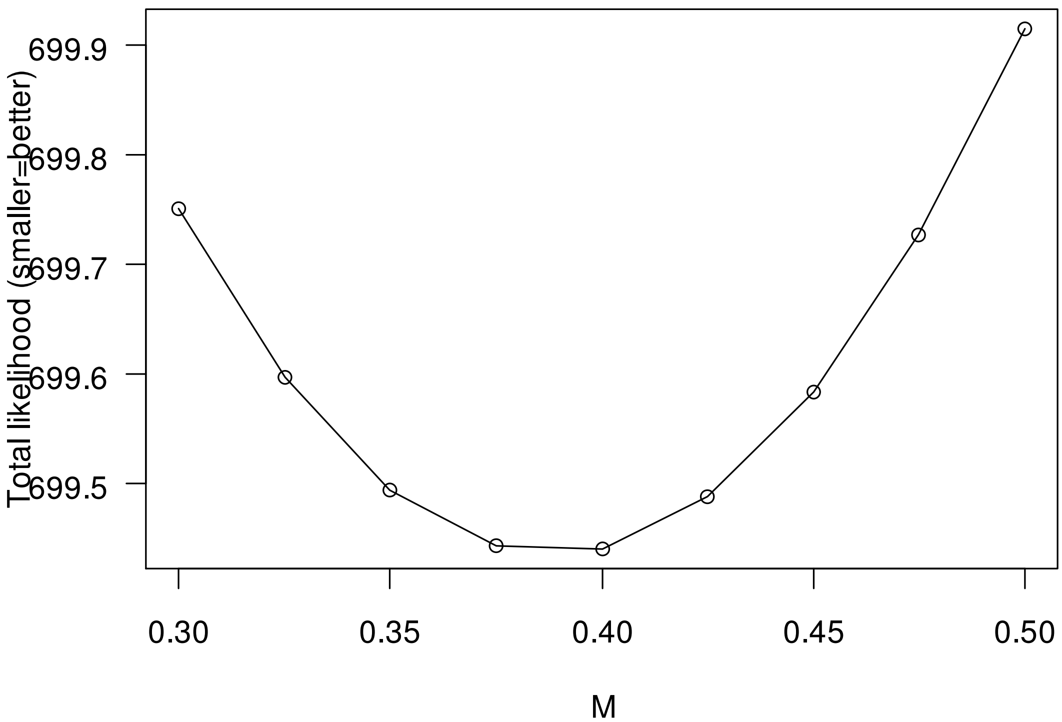
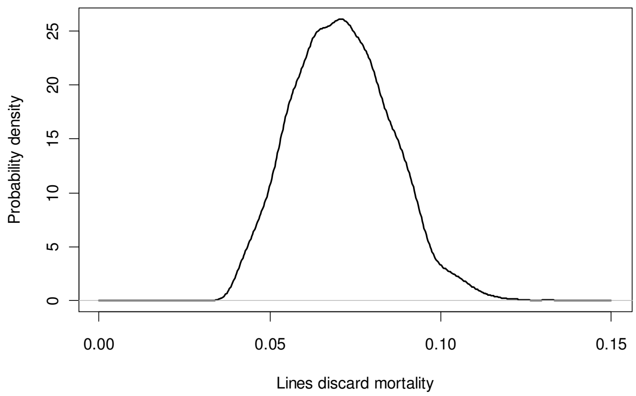
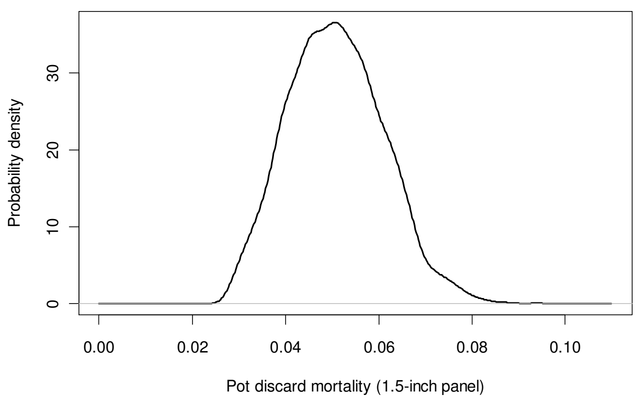


Figure 7. Distributions of parameters subjected to variability during the mixed Monte Carlo and bootstrap procedure. These parameters include discard mortality, natural mortality, and weight on indices of abundance. The three discard mortality distributions differ only by scale.





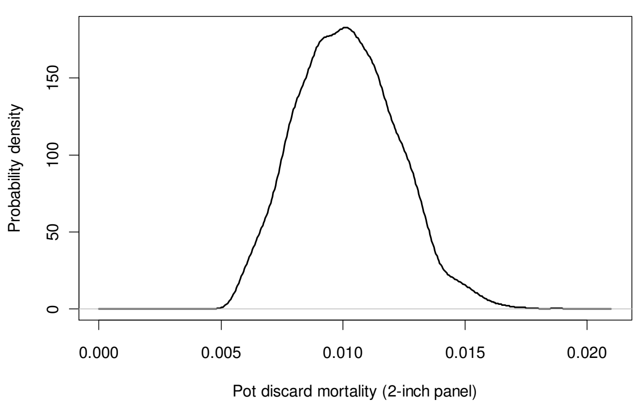
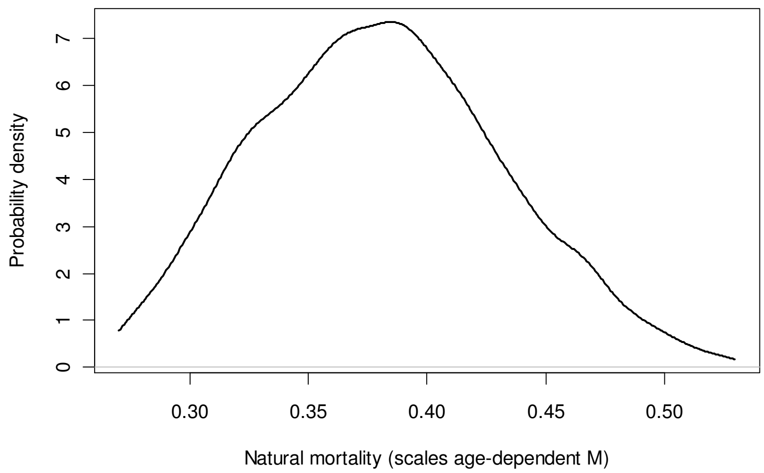
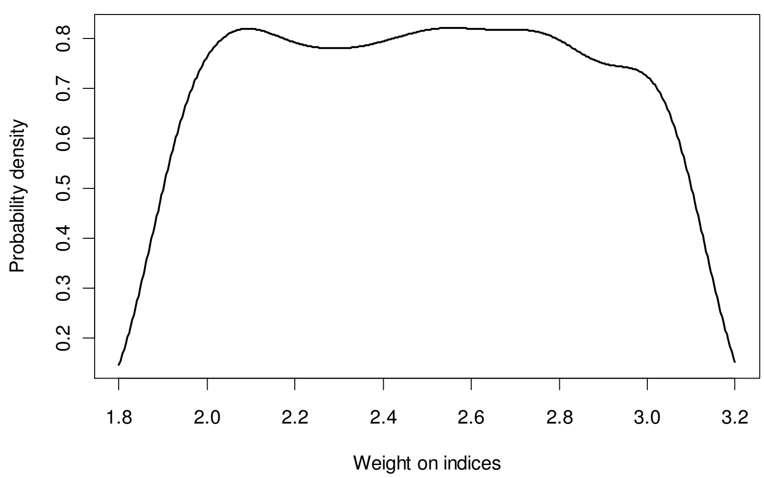


Figure 7 (cont.)





Fgiure 8. Standard errors of management quantities as a function of the number of Monte Carlo/bootstrap iterations.

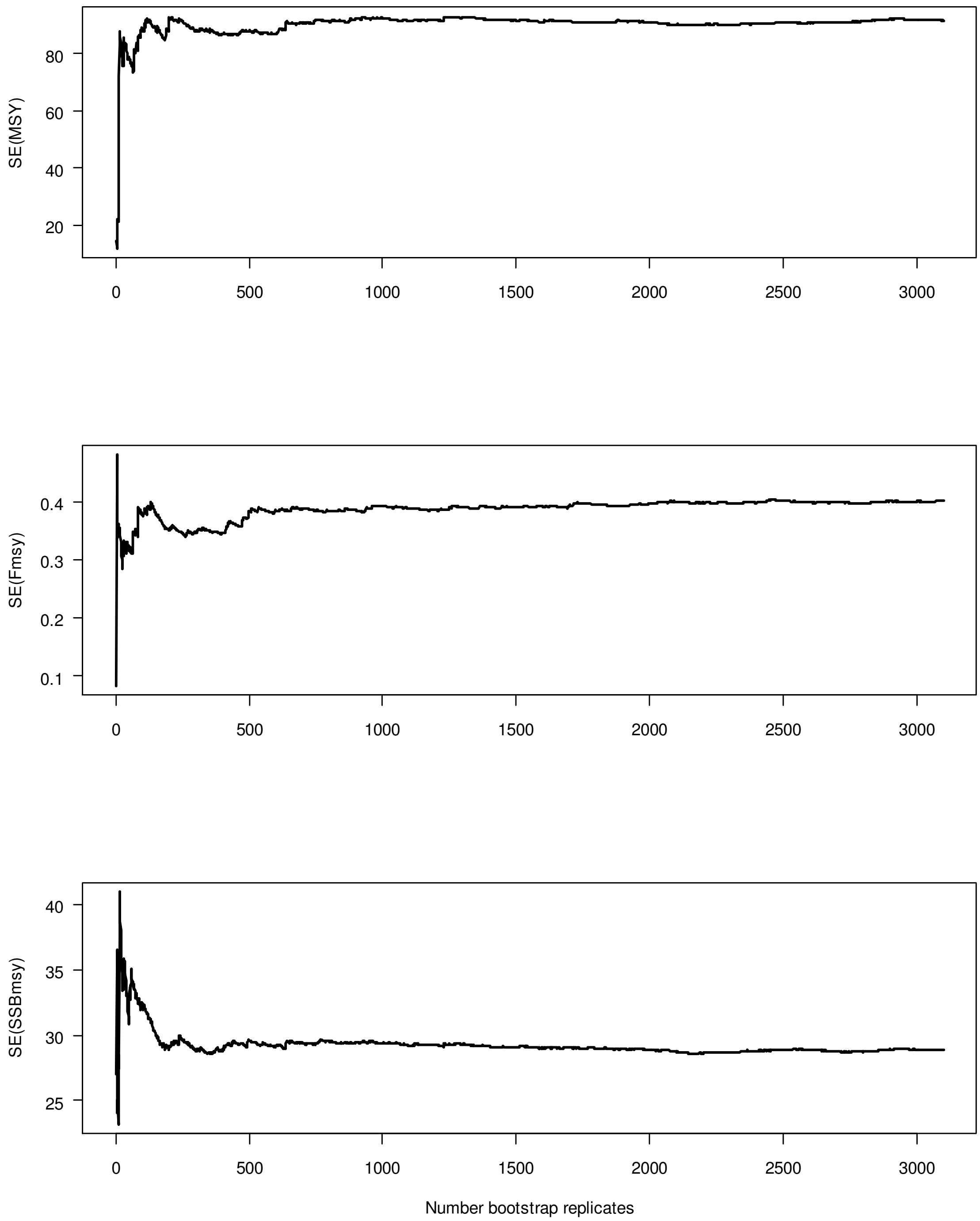
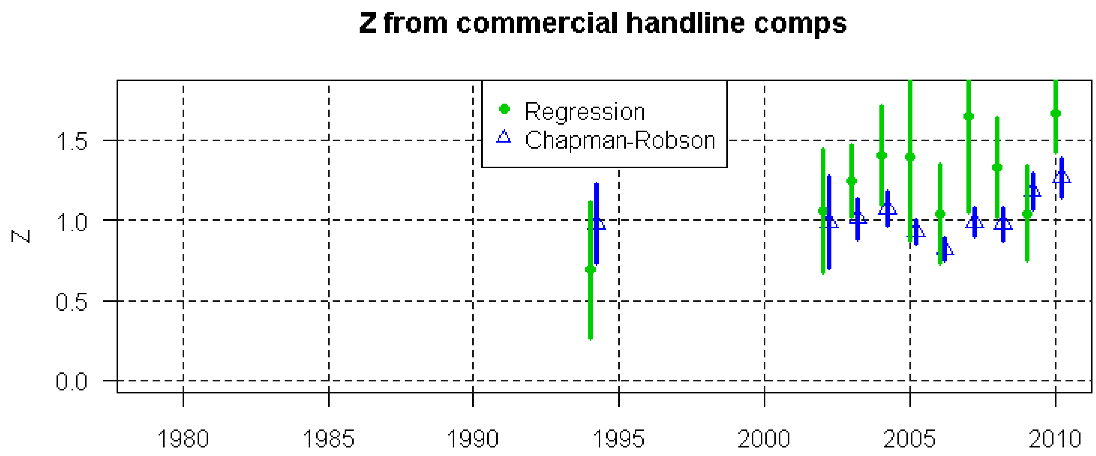


Figure 9. Catch curve analysis of commercial handline and trap data.



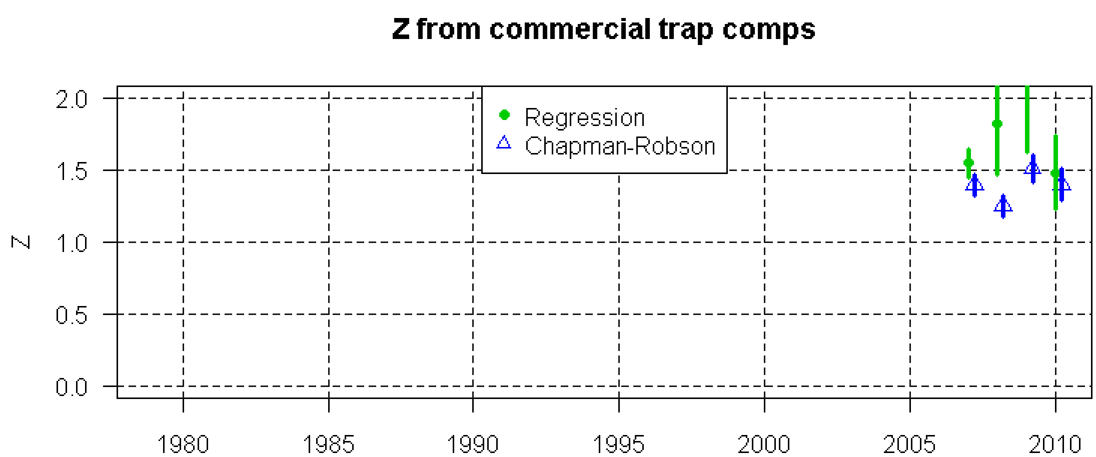


Figure 10. Catch curve analysis of headboat and MARMAP data.