Development and diagnostics of the Beaufort assessment model applied to Cobia

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Development and diagnostics of the Beaufort assessment model applied to cobia

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1. Introduction

The BAM, a statistical catch-age formulation, was applied to South Atlantic cobia as the primary stock assessment model. The model is detailed in SEDAR28-RW01, 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 cobia, CVs of combined 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 in Francis (2011).

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 for length composition data and the number of fish measured annually for age composition data. Number of trips was not available for age composition data, and the AW panel believed the number of fish was a reasonable approximation of the number of trips because cobia are caught primarily as one fish per trip.

Using these initial weights, the BAM was fit to the data. In this model run, the CV of length at age hit its lower bound (0.05), recruitment variability was high (σ_R=0.85), and fits to the indices were poor, particularly in the terminal year when the indices were underestimated by 50-100% (Figure 1, left panel). This suggests signals from the composition data were overwhelming those from the indices, 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 S6 in the AW report).

2.2. *Model run with iterative re-weighting*

From this initial fit, standard deviations of normalized residuals (SDNRs) were computed. 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, normalized residuals for each year (*y*) were 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 *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.

This method typically results in down-weighting of composition data relative to indices (Francis 2011) and has been used in prior SEDAR assessments (SEDAR25-RW04, SEDAR25-RW06). The method does not account for potential correlations in composition data, however, and so composition data may still be given too much weight. Therefore, a variation of this method that accounts for potential correlations in composition data was applied. The method is described in Appendix A of Francis (2011) and involves modifying the standard error (s.e.) by which residuals for each year are normalized. Method TA1.8 in Table A1 of Francis (2011) was used where the s.e. is computed as,

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

Here, N_y is the assumed sample size, and $\mu_{exp,iy}$ is the expected proportion of fish in the ith length or age bin in year y with associated length or age x_i. The mean expected value is computed as,

$$\mu_{exp,y} = \sum_i x_i \mu_{exp,i,y}$$

Otherwise, the method is identical to that described above.

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 pooled commercial age composition and length composition were available, and so the weights for these two data sources was set equal to those from the corresponding recreational data source.

Following the above procedure, model components were iteratively re-weighted until SDNRs were near 1.0 (Table 1). Accounting for correlations in the composition data had only modest effects on the computed weights (Figure 2). Weights accounting for correlations were used in the base run. Compared to the model without re-weighting, the model with iterative re-weighting showed improvement in the fits to indices, particularly in the later years, and slight improvements in fits to the composition data (Figure 1, right panel). The estimated CV in length at age was more reasonable (0.128) as was estimates of recruitment variability (σ_R=0.61). This model run was considered the base run in the assessment.

2.3. *Sensitivity runs and iterative re-weighting*

The influence of the indices on indicators of stock status was evaluated via sensitivity analysis (sensitivities S13-15). For each sensitivity run, the iterative re-weighting procedure described above was repeated for the particular combination of data sources included in the sensitivity run. There were only minor differences in likelihood weights for runs with single and multiple indices (Figure 3).

3. Model diagnostics

3.1. *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 4). For example, strong year classes of cobia were predicted in 1988, 1991, 1994, 1999, 2000, and 2005.

3.2. *Likelihood profiles*

Likelihood profiles were computed for steepness and R0 (Figure 5, Table 2, 3). The profile on steepness did not show minimum, with the most likely values at the upper bound, indicating the data were not informative regarding steepness. Steepness was fixed at a value of 0.75 in the base run of the assessment model. Sensitivity runs were conducted at values of 0.6 and 0.9, which span the range of plausible values based on the profile. The profile on R0 showed a minimum near the estimated value, but it was not well-defined, indicating that the data provided only weak information on R0.

3.3. *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 6. The bootstrap procedure on landings, indices, age compositions, and length compositions is also described in the assessment report (bootstrapped data sets not shown).

The MCB procedure re-fit *n*=3200 trials that differed from the original inputs. This number of trials was sufficient for convergence of standard errors in estimated management quantities (Figure 7).

3.4 *Catch curve analysis*

In addition to the traditional method of catch curve analysis described in the AW report, catch curve analysis was also conducted using a method developed by Thorson and Prager (2011) (Figure 8-9). In addition to estimating total mortality, this method simultaneously estimates logistic selectivity parameters from the ascending limb of the catch curve, avoiding the need to choose an age at full selection from visual inspection. The method also relaxes the assumption of constant natural mortality for all vulnerable ages by assuming Lorenzen age-based natural mortality, with M decreasing with increasing age. The same age-based natural mortality vector used in the BAM was applied to the Thorson and Prager (2011) method of catch curve analysis.

Perhaps the strongest assumption behind catch curve analysis 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. These 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.

Estimates of F (calculated as F=Z-M, where M=0.26) from the Thorson and Prager (2011) method were generally < 0.2 (Figure 8). This range was consistent with estimates of mortality from the BAM. Patterns in selectivity estimated from the Thorson and Prager (2011) method suggested age at full selection at age three or four in most years, similar to that estimated by the BAM (Figure 9).

3.5 Surplus Production Model (ASPIC)

A logistic age-aggregated surplus production model, implemented in ASPIC (Prager 2005), was considered for cobia by the AW panel, but failed to converge or hit bounds under a variety of configurations (Table 4). In general, estimates of B1/K for models that did converge were very low (e.g., < 0:0.01) and were considered highly unrealistic by the AW panel for a species with little directed harvest. The primary issue was a lack of contrast in the available data with which to estimate the production function for cobia. While the production model did converge under a restrictive set of conditions (described in the AW report), the AW panel recommended the BAM as the primary assessment model most useful for providing management advice.

4. Literature cited

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

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

Thorson, J.T., and M.H. Prager. 2011. Better catch curves: Incorporating age-specific natural mortality and logistic selectivity. Trans. Am. Fish. Soc. 140:356−366.

Table 1. SDNRs and weights computed in model fits for the base run (accounting for correlations in composition data as described in the text). The component weights from the final iteration are shaded. Indices represented are Headboat (HB), South Carolina logbook (SClog), and MRFSS (not used in base run but included in sensitivity analysis). Fisheries represented are the general recreational fleet (Rec_pool). Weights for the general commercial fleet (not shown) were set equal to the corresponding weights for the recreational fleet.

		SDNR				Weights				Cum. weights (for next iteration)			
Run	Source	HB	SClog	MRFSS	Rec_pool	HB	SClog	MRFSS	Rec_pool	HB	SClog	MRFSS	Rec_pool
a	CPUE	2.95596	1.56689	-		0.33830	0.63821	-	-	0.33830	0.63821	-	-
	Length comps	-	-	-	3.11679	-	-	-	0.10294	-	-	-	0.10294
	Age comps	-	-	-	4.09555	-	-	-	0.05962	-	-	-	0.05962
b	CPUE	0.69475	0.53829			1.43936	1.85774	-	-	0.48694	1.18563	-	-
	Length comps				0.90824	-	-	-	1.21226	-	-	-	0.12479
	Age comps				0.65092	-	-	-	2.36015	-	-	-	0.14071
c	CPUE	0.97524	1.17122			1.02539	0.85381	-	-	0.49930	1.01230	-	-
	Length comps				1.01303	-	-	-	0.97443	-	-	-	0.12160
	Age comps				0.86902	-	-	-	1.32415	-	-	-	0.18632
d	CPUE	1.01174	1.06147			0.98840	0.94209	-	-	0.49351	0.95368	-	-
	Length comps				1.02121	-	-	-	0.95889	-	-	-	0.11660
	Age comps				0.97063	-	-	-	1.06144	-	-	-	0.19776
e	CPUE	1.005	1.018										
	Length comps				1.005								
	Age comps				0.991								

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, cA=general commercial, mrip=general recreational, hb=headboat, and sc=South Carolina logbook.

h	nLL(data)	nLL(penalized)	nLL(SR)	U.sc	U.hb	len.cA	len.mrip	age.cA	age.mrip
0.1	223792	228755.8	4875.524	50.483	64.582	-84.129	-2655.31	-16.027	-47.991
0.15	-3655.43	-3633.309	22.113	3.583	3.698	-89.512	-3099.41	-16.878	-457.245
0.2	-3660.71	-3650.979	9.722	2.976	7.271	-89.422	-3098.52	-16.803	-466.248
0.25	-3660.71	-3650.979	9.722	2.976	7.271	-89.422	-3098.52	-16.803	-466.248
0.3	-3664.55	-3657.148	7.387	2.327	6.049	-89.493	-3099.78	-16.844	-466.85
0.35	-3667.06	-3660.956	6.088	2.019	5.3	-89.532	-3100.85	-16.864	-467.18
0.4	-3668.66	-3663.382	5.262	1.868	4.851	-89.554	-3101.67	-16.874	-467.33
0.45	-3669.7	-3664.995	4.683	1.791	4.578	-89.566	-3102.28	-16.879	-467.388
0.5	-3670.39	-3666.114	4.251	1.75	4.407	-89.574	-3102.72	-16.882	-467.403
0.55	-3670.86	-3666.923	3.915	1.727	4.295	-89.579	-3103.06	-16.884	-467.401
0.6	-3671.2	-3667.528	3.647	1.714	4.22	-89.582	-3103.31	-16.885	-467.391
0.65	-3671.45	-3667.994	3.428	1.706	4.167	-89.584	-3103.51	-16.886	-467.379
0.7	-3671.64	-3668.362	3.245	1.702	4.129	-89.585	-3103.66	-16.887	-467.367
0.75	-3671.78	-3668.658	3.092	1.699	4.1	-89.587	-3103.78	-16.887	-467.356
0.8	-3671.89	-3668.902	2.961	1.698	4.078	-89.587	-3103.87	-16.888	-467.347
0.85	-3671.98	-3669.104	2.849	1.697	4.061	-89.588	-3103.95	-16.888	-467.339
0.9	-3672.06	-3669.274	2.751	1.697	4.047	-89.589	-3104.02	-16.888	-467.333
0.95	-3672.12	-3669.42	2.666	1.697	4.036	-89.589	-3104.07	-16.888	-467.327

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, cA=general commercial, mrip=general recreational, hb=headboat, and sc=South Carolina logbook.

R0	nLL(data)	nLL(penalized)	nLL(SR)	U.sc	U.hb	len.cA	len.mrip	age.cA	age.mrip
10000	-1345.782	-1017.036	328.746	3.839	9.054	-89.619	-3067.628	-16.861	-375.308
20000	-3547.108	-3350.934	196.174	6.123	9.861	-89.617	-3082.906	-16.874	-403.442
30000	-3616.068	-3487.884	128.184	5.977	9.618	-89.631	-3089.448	-16.869	-437.434
40000	-3567.866	-3471.355	96.511	5.649	8.829	-89.629	-3091.909	-16.869	-448.293
50000	-3587.429	-3519.123	68.305	5.353	8.214	-89.628	-3093.888	-16.867	-454.484
60000	-3600.415	-3551.653	48.761	4.999	7.739	-89.626	-3095.836	-16.872	-459.607
70000	-3610.038	-3575.675	34.362	4.641	7.289	-89.623	-3097.542	-16.875	-463.587
80000	-3662.644	-3639.409	23.235	4.311	6.911	-89.617	-3100.279	-16.877	-467.81
90000	-3667.014	-3650.99	16.025	3.794	6.44	-89.612	-3101.614	-16.879	-469.641
1.00E+05	-3669.941	-3659.003	10.939	3.193	5.918	-89.607	-3102.615	-16.882	-470.261
110000	-3671.65	-3664.157	7.493	2.603	5.369	-89.601	-3103.271	-16.883	-470.045
120000	-3672.34	-3667.124	5.216	2.129	4.841	-89.595	-3103.631	-16.885	-469.29
130000	-3672.212	-3668.468	3.745	1.816	4.368	-89.589	-3103.759	-16.886	-468.208
140000	-3671.454	-3668.629	2.825	1.662	3.968	-89.583	-3103.705	-16.886	-466.935
150000	-3670.229	-3667.947	2.281	1.638	3.642	-89.577	-3103.507	-16.887	-465.562
160000	-3668.674	-3666.678	1.996	1.711	3.385	-89.571	-3103.199	-16.887	-464.146
170000	-3666.899	-3665.012	1.888	1.851	3.19	-89.565	-3102.808	-16.887	-462.724
180000	-3664.988	-3663.088	1.9	2.032	3.046	-89.559	-3102.357	-16.887	-461.321
190000	-3664.988	-3663.088	1.9	2.032	3.046	-89.559	-3102.357	-16.887	-461.321
2.00E+05	-3660.991	-3658.851	2.14	2.454	2.879	-89.548	-3101.342	-16.886	-458.63
210000	-3658.984	-3656.661	2.323	2.671	2.842	-89.544	-3100.804	-16.886	-457.354
220000	-3657.006	-3654.478	2.528	2.883	2.826	-89.539	-3100.26	-16.886	-456.129
230000	-3655.071	-3652.325	2.746	3.087	2.827	-89.535	-3099.714	-16.885	-454.954

Table 3 (cont)

R0	nLL(data)	nLL(penalized)	nLL(SR)	U.sc	U.hb	len.cA	len.mrip	age.cA	age.mrip
240000	-3653.19	-3650.221	2.969	3.28	2.84	-89.53	-3099.173	-16.885	-453.83
250000	-3651.37	-3648.175	3.195	3.462	2.863	-89.526	-3098.641	-16.884	-452.755
260000	-3649.614	-3646.195	3.419	3.632	2.893	-89.523	-3098.119	-16.884	-451.726
270000	-3647.923	-3644.283	3.64	3.791	2.928	-89.519	-3097.61	-16.883	-450.742
280000	-3646.298	-3642.442	3.856	3.939	2.967	-89.516	-3097.115	-16.883	-449.801
290000	-3644.737	-3640.671	4.066	4.076	3.007	-89.513	-3096.635	-16.883	-448.901
3.00E+05	-3643.239	-3638.97	4.269	4.203	3.049	-89.51	-3096.17	-16.882	-448.039
310000	-3641.803	-3637.337	4.466	4.321	3.092	-89.507	-3095.721	-16.882	-447.214
320000	-3640.425	-3635.77	4.656	4.431	3.134	-89.504	-3095.288	-16.881	-446.423
330000	-3639.105	-3634.265	4.839	4.533	3.176	-89.502	-3094.87	-16.881	-445.666
340000	-3637.838	-3632.822	5.016	4.628	3.218	-89.499	-3094.466	-16.88	-444.939
350000	-3636.622	-3631.437	5.185	4.716	3.259	-89.497	-3094.077	-16.88	-444.241
360000	-3635.456	-3630.107	5.349	4.798	3.298	-89.495	-3093.703	-16.88	-443.572
370000	-3634.337	-3628.831	5.506	4.875	3.337	-89.493	-3093.342	-16.879	-442.928
380000	-3633.262	-3627.604	5.657	4.946	3.374	-89.491	-3092.994	-16.879	-442.31
390000	-3632.229	-3626.426	5.803	5.013	3.41	-89.489	-3092.659	-16.878	-441.715
4.00E+05	-3631.236	-3625.293	5.943	5.076	3.445	-89.487	-3092.336	-16.878	-441.143
410000	-3630.282	-3624.204	6.078	5.134	3.478	-89.485	-3092.024	-16.878	-440.591
420000	-3629.363	-3623.156	6.208	5.189	3.51	-89.483	-3091.724	-16.877	-440.06
430000	-3628.479	-3622.146	6.333	5.241	3.541	-89.482	-3091.435	-16.877	-439.548
440000	-3627.627	-3621.175	6.453	5.29	3.571	-89.48	-3091.155	-16.877	-439.054
450000	-3626.807	-3620.238	6.569	5.335	3.6	-89.479	-3090.886	-16.876	-438.577
460000	-3626.016	-3619.335	6.681	5.378	3.627	-89.477	-3090.625	-16.876	-438.116
470000	-3625.253	-3618.464	6.789	5.419	3.654	-89.476	-3090.374	-16.876	-437.671
480000	-3624.517	-3617.624	6.893	5.457	3.679	-89.475	-3090.131	-16.875	-437.241

Table 3 (cont)

R0	nLL(data)	nLL(penalized)	nLL(SR)	U.sc	U.hb	len.cA	len.mrip	age.cA	age.mrip
490000	-3623.806	-3616.813	6.993	5.494	3.703	-89.473	-3089.897	-16.875	-436.824
5.00E+05	-3623.119	-3616.029	7.09	5.528	3.726	-89.472	-3089.67	-16.875	-436.421
510000	-3622.455	-3615.272	7.183	5.56	3.748	-89.471	-3089.451	-16.875	-436.031
520000	-3621.813	-3614.539	7.274	5.591	3.77	-89.47	-3089.239	-16.874	-435.652
530000	-3621.192	-3613.831	7.361	5.619	3.79	-89.469	-3089.034	-16.874	-435.285
540000	-3620.591	-3613.146	7.445	5.647	3.809	-89.467	-3088.835	-16.874	-434.929
550000	-3620.009	-3612.483	7.526	5.673	3.828	-89.466	-3088.642	-16.873	-434.584
560000	-3619.445	-3611.84	7.605	5.697	3.846	-89.465	-3088.456	-16.873	-434.248
570000	-3618.898	-3611.218	7.68	5.72	3.862	-89.464	-3088.275	-16.873	-433.922
580000	-3618.368	-3610.614	7.754	5.742	3.878	-89.463	-3088.1	-16.873	-433.604
590000	-3617.854	-3610.029	7.824	5.763	3.893	-89.463	-3087.931	-16.872	-433.296
6.00E+05	-3617.354	-3609.462	7.892	5.783	3.908	-89.462	-3087.766	-16.872	-432.995
610000	-3616.87	-3608.911	7.958	5.801	3.921	-89.461	-3087.606	-16.872	-432.701
620000	-3616.399	-3608.377	8.022	5.818	3.934	-89.46	-3087.451	-16.872	-432.415
630000	-3615.941	-3607.858	8.083	5.835	3.946	-89.459	-3087.301	-16.871	-432.136
640000	-3615.496	-3607.354	8.141	5.85	3.957	-89.458	-3087.155	-16.871	-431.863
650000	-3615.062	-3606.865	8.198	5.864	3.967	-89.457	-3087.013	-16.871	-431.595
660000	-3614.64	-3606.389	8.251	5.877	3.976	-89.457	-3086.875	-16.871	-431.332
670000	-3614.229	-3605.926	8.303	5.889	3.983	-89.456	-3086.742	-16.87	-431.074
680000	-3613.828	-3605.477	8.351	5.899	3.99	-89.455	-3086.612	-16.87	-430.819
690000	-3613.435	-3605.039	8.396	5.907	3.994	-89.454	-3086.486	-16.87	-430.566
7.00E+05	-3613.05	-3604.614	8.436	5.913	3.996	-89.453	-3086.364	-16.869	-430.311

Table 4. Summary of model runs for age aggregated surplus production model for South Atlantic cobia.

Iteration	Start Year	Indices	Error Type	MC	B1/K	MSY	K	q	flags (est or fix)	Min MSY	Max MSY	Min K	Max K	Comments
1	1955	HB, MRFSS, SC	SSE	N	0.9	6.4d5	2d7	5d-8	estimate	1d3	1d7	1.1d7	1d8	Unrealistic B1/K estimated (0.01)
2	1955	HB, MRFSS, SC	SSE	N	0.9	6.4d5	2d7	5d-8	fixed	1d3	1d7	1.1d7	1d8	K at upper bound
3	1955	HB, MRFSS, SC	SSE	N	0.9	6.4d5	2d7	5d-8	fixed	1d3	1d7	1.1d7	1d9	K at upper bound
4	1955	HB, MRFSS, SC	SSE	N	0.9	6.4d5	2d7	5d-8	fixed	1d3	1d7	1.1d7	1d10	K at lower bound
5	1955	HB, MRFSS, SC	SSE	N	0.9	6.4d5	2d7	5d-8	fixed	1d3	1d8	1.1d8	1d10	q at upper bound
6	1955	HB, MRFSS, SC	LAV	Y	0.9	6.4d5	2d7	5d-8	fixed	1d3	1d8	1.1d8	1d10	q at upper bound
7	1981	HB, MRFSS, SC	SSE	N	0.9	6.4d5	2d7	5d-8	estimated	1d3	1d8	1.1d8	1d10	K at upper bound
8	1981	HB, MRFSS, SC	SSE	N	0.9	6.4d5	2d7	5d-8	fixed	1d3	1d8	1.1d8	1d10	q at upper bound
9	1981	HB, MRFSS, SC	LAV	Y	0.9	6.4d5	2d7	5d-8	fixed	1d3	1d8	1.1d8	1d10	q at upper bound
10	1981	HB, MRFSS, SC	LAV	Y	0.7	6.4d5	2d7	5d-8	fixed	1d3	1d7	1.1d7	1d9	MSY at upper bound
11	1981	HB, MRFSS, SC	LAV	Y	0.8	6.4d5	2d8	5d-8	fixed	1d3	1d8	1.1d8	1d10	q at upper bound
12	1981	HB, MRFSS, SC	SSE	N	0.5	6.4d5	2d8	5d-8	fixed	1d3	1d8	1.1d8	1d10	K at lower bound
13	1981	HB, MRFSS, SC	SSE	Y	0.6	6.4d5	2d8	5d-8	estimated	1d3	2d8	1.1d7	1d9	low B1/K (0.12)), but no bound issues
14	1981	HB, MRFSS, SC	SSE	Y	0.5	6.4d5	2d8	5d-8	estimated	1d3	1d7	1.1d7	1d9	low B1/K (0.12)), but no bound issues
15	1981	HB, MRFSS, SC	SSE	Y	0.4	6.4d5	2d8	5d-8	estimated	1d3	1d7	1.1d7	1d9	low B1/K (0.12)), but no bound issues
16	1981	HB, MRFSS, SC	SSE	Y	0.7	6.4d5	2d8	5d-8	estimated	1d3	1d7	1.1d7	1d9	low B1/K (0.12)), but no bound issues
17	1981	HB, MRFSS, SC	SSE	Y	0.8	6.4d5	2d8	5d-8	estimated	1d3	1d7	1.1d7	1d9	low B1/K (0.12)), but no bound issues
18	1981	HB, MRFSS, SC	SSE	Y	0.9	6.4d5	2d8	5d-8	estimated	1d3	1d7	1.1d7	1d9	low B1/K (0.12)), but no bound issues
19	1981	HB, MRFSS, SC	SSE	Y	0.5	6.4d5	2d8	5d-8	fixed	1d3	1d7	1.1d7	1d9	MSY at upper bound
20	1981	HB only	SSE	Y	0.5	6.4d5	2d8	5d-8	estimated	1d3	1d7	1.1d7	1d9	MSY at upper bound
21	1981	HB only	SSE	Y	0.7	6.4d5	2d8	5d-8	estimated	1d3	1d7	1.1d7	1d9	MSY at upper bound
22	1981	MRFSS, SC	SSE	Y	0.5	6.4d5	2d8	5d-8	estimated	1d3	1d7	1.1d7	1d9	K at lower bound
23	1981	MRFSS, SC	SSE	Y	0.6	6.4d5	2d8	5d-8	estimated	1d3	5d6	5.1d6	1d9	very low B1/K (0.04)
24	1981	MRFSS, SC	SSE	Y	0.6	6.4d5	2d8	5d-8	fixed	1d3	5d6	5.1d6	1d9	MSY at upper bound
25	1981	MRFSS, SC	SSE	Y	0.6	6.4d5	2d8	5d-8	fixed	1d3	1d7	1.1d7	1d9	MSY at upper bound
26	1981	MRFSS, SC	SSE	Y	0.6	6.4d5	2d8	5d-8	fixed	1d3	9d7	9.1d7	1d9	K at upper bound
27	1981	MRFSS, SC	SSE	Y	0.6	6.4d5	2d8	5d-8	fixed	1d3	9d7	9.1d7	9d9	q at upper bound
28	1981	MRFSS, SC	SSE	Y	0.6	6.4d5	2d8	5d-4	fixed	1d3	9d7	9.1d7	9d9	q at upper bound
29	1981	HB, MRFSS, SC	SSE	Y	0.7	6.4d5	2d8	5d-6	estimated	1d3	1d7	1.1d7	1d9	low B1/K (0.12)), but no bound issues
30	1981	HB, MRFSS, SC	SSE	Y	0.7	6.4d5	2d8	1d-5	estimated	1d3	1d7	1.1d7	1d9	q at upper or lower bound
31	1981	HB, MRFSS, SC	SSE	Y	0.7	6.4d5	2d8	1d-6	estimated	1d3	1d7	1.1d7	1d9	low B1/K (0.12)), but no bound issues
32	1981	HB, MRFSS, SC	SSE	N	0.7	6.4d5	2d8	1d-6	estimated	1d3	1d7	1.1d7	1d9	low B1/K (0.12)), but no bound issues
33	1981	HB, MRFSS, SC	LAV	N	0.7	6.4d5	2d8	1d-6	estimated	1d3	1d7	1.1d7	1d9	low B1/K (0.18)), unrealistic results
34	1981	HB, MRFSS, SC	LAV	Y	0.7	6.4d5	2d8	1d-6	estimated	1d3	1d7	1.1d7	1d9	low B1/K (0.18)), unrealistic results
35	1981	HB, MRFSS, SC	SSE	Y	0.2	6.4d5	2d8	1d-6	estimated	1d3	1d7	1.1d7	1d9	low B1/K (0.12)), but no bound issues

Table 4. (continued)

Iteration	Start Year	Indices	Error Type	MC	B1/K	MSY	K	q	flags (est or fix)	Min MSY	Max MSY	Min K	Max K	Comments
36	1981	HB, MRFSS, SC	SSE	Y	0.1	6.4d5	2d8	1d-6	estimated	1d3	1d7	1.1d7	1d9	low B1/K (0.12)), but no bound issues
37	1981	HB, MRFSS, SC	SSE	Y	0.15	6.4d5	2d8	1d-6	fixed	1d3	1d7	1.1d7	1d9	unrealistic increase in biomass with low, stable F
38	1981	HB, MRFSS, SC	SSE	Y	0.25	6.4d5	2d8	1d-6	fixed	1d3	1d7	1.1d7	1d9	q at upper or lower bound
39	1981	HB, MRFSS, SC	SSE	Y	0.25	6.4d5	2d8	5d-8	fixed	1d3	1d7	1.1d7	1d9	q at upper or lower bound
40	1981	HB, MRFSS, SC	SSE	Y	0.1	6.4d5	2d8	5d-6	fixed	1d3	1d7	1.1d7	1d9	q at upper or lower bound
41	1981	HB, MRFSS, SC	SSE	Y	0.2	6.4d5	2d8	5d-6	fixed	1d3	1d7	1.1d7	1d9	q at upper bound
42	1981	HB, MRFSS, SC	SSE	Y	0.2	6.4d5	2d8	5d-8	fixed	1d3	1d7	1.1d7	1d9	MSY at upper bound
43	1981	HB, MRFSS, SC	SSE	Y	0.15	6.4d5	2d8	5d-7	fixed	1d3	1d7	1.1d7	1d9	MSY at upper bound
44	1981	HB, MRFSS, SC	SSE	Y	0.15	6.4d5	2d8	5d-6	fixed	1d3	1d7	1.1d7	1d9	MSY at upper bound
45	1981	HB, MRFSS, SC	SSE	Y	0.18	6.4d5	2d8	5d-6	fixed	1d3	1d7	1.1d7	1d9	MSY at upper bound
46	1981	HB, MRFSS, SC	SSE	Y	0.12	6.4d5	2d8	5d-6	fixed	1d3	1d7	1.1d7	1d9	low estimate B1/K (0.12)
47	1981	HB, MRFSS, SC	SSE	Y	0.2	6.4d5	2d8	5d-6	fixed	1d3	1d7	1.1d7	1d9	q at upper or lower bound
48	1981	HB	SSE	Y	0.5	6.4d5	2d8	5d-8	estimated	1d3	1d7	1.1d7	1d9	MSY at upper bound
49	1981	HB	SSE	Y	0.1	6.4d5	2d8	5d-8	fixed	1d3	1d7	1.1d7	1d9	K at lower bound
50	1981	MRFSS	SSE	Y	0.5	6.4d5	2d8	5d-8	estimated	1d3	1d7	1.1d7	1d9	K at lower bound
51	1981	MRFSS	SSE	Y	0.5	6.4d5	2d7	5d-8	estimated	1d3	1d6	1.1d6	1d9	ended normally, very low B1/K (0.04)
52	1981	HB	SSE	Y	0.5	6.4d5	2d7	5d-8	estimated	1d3	1d6	1.1d6	1d9	MSY at upper bound
53	1981	HB	SSE	Y	0.5	6.4d5	2d7	5d-8	estimated	1d3	9d6	9.1d6	1d9	MSY at upper bound
54	1981	HB	SSE	Y	0.5	6.4d5	2d7	5d-9	estimated	1d3	1d7	1.1d6	1d9	MSY at upper bound
55	1981	SC Charter logbook	SSE	Y	0.5	6.4d5	2d7	5d-8	estimated	1d3	1d6	1.1d6	1d9	MSY at lower bound
56	1981	HB	SSE	Y	0.1	6.4d5	2d8	5d-8	fixed	1d3	0.5d7	0.51d7	1d9	MSY at upper bound
57	1981	HB	SSE	Y	0.1	6.4d5	2d8	5d-8	fixed	1d3	2d7	2.1d7	1d9	MSY at upper bound
58	1955	HB, MRFSS, SC	SSE	Y	0.9	6.4d5	2d8	5d-8	estimate	1d3	1d7	1.1d7	1d9	unrealistic, B1/K = 0.001
59	1955	HB, MRFSS, SC	SSE	Y	0.9	6.4d5	2d8	5d-8	fixed	1d3	1d7	1.1d7	1d9	K at upper bound
60	1955	HB, MRFSS, SC	SSE	Y	0.9	6.4d5	2d8	5d-8	fixed	1d3	1d7	1.1d7	1d10	q at bound
61	1981	HB split, MRFSS split, SC	SSE	Y	0.5	6.4d5	2d8	1d-6	estimated	1d3	1d7	1.1d7	1d9	K or MSY at bound
62	1981	HB split, MRFSS split, SC	SSE	Y	0.4	6.4d5	2d8	1d-6	fixed	1d3	1d7	1.1d7	1d9	K or MSY at bound
63	1981	HB split, MRFSS split, SC	SSE	Y	0.25	6.4d5	2d8	1d-6	estimated	1d3	1d7	1.1d7	1d9	K or MSY at bound
64	1981	HB split, MRFSS split (1st -9 q), SC	SSE	Y	0.25	6.4d5	2d8	1d-6	estimated	1d3	1d7	1.1d7	1d9	K or MSY at bound
65	1981	HB split, MRFSS split (1st -9 q), SC	SSE	Y	0.25	6.4d5	2d8	1d-6	estimated	1d3	1d7	1.1d7	1d9	K or MSY at bound
66	1981	HB split, MRFSS 2nd only), SC	SSE	Y	0.25	6.4d5	2d8	1d-6	estimated	1d3	1d7	1.1d7	1d9	K or MSY at bound
67	1981	MRFSS and SC only	SSE	Y	0.25	6.4d5	2d8	1d-6	estimated	1d3	1d7	1.1d7	1d9	K or MSY at bound
68	1981	HB split, MRFSS 2nd only), SC	SSE	Y	0.8	6.4d5	2d8	1d-6	fixed	1d3	1d7	1.1d7	1d9	K or MSY at bound
69	1981	HB split, MRFSS 2nd only), SC	SSE	Y	0.7	6.4d5	2d8	1d-6	fixed	1d3	1d7	1.1d7	1d9	K or MSY at bound
70	1955	HB, SC	SSE	Y	0.7	6.45	2d8	1d-6	estimated	1d3	1d7	1.1d7	1d9	Msy at upper bound
71	1985	HB, SC	LAV	Y	0.5	6.4d5	2d8	1d-6	fixed	1d3	1d6	1.1d6	1d8	converged with B1/K fixed at 0.5

Figure 1. Fits to indices, age compositions, and length compositions for model runs without iterative re-weighting (left panel, all component weights set to 1.0) and with iterative re-weighting (right panel, accounting for correlations in composition data). Data set indicated above each panel (hb=headboat index, sc=South Carolina logbook index). Bottom panels show the measure of fit to annual age and length compositions. Shown is the 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.

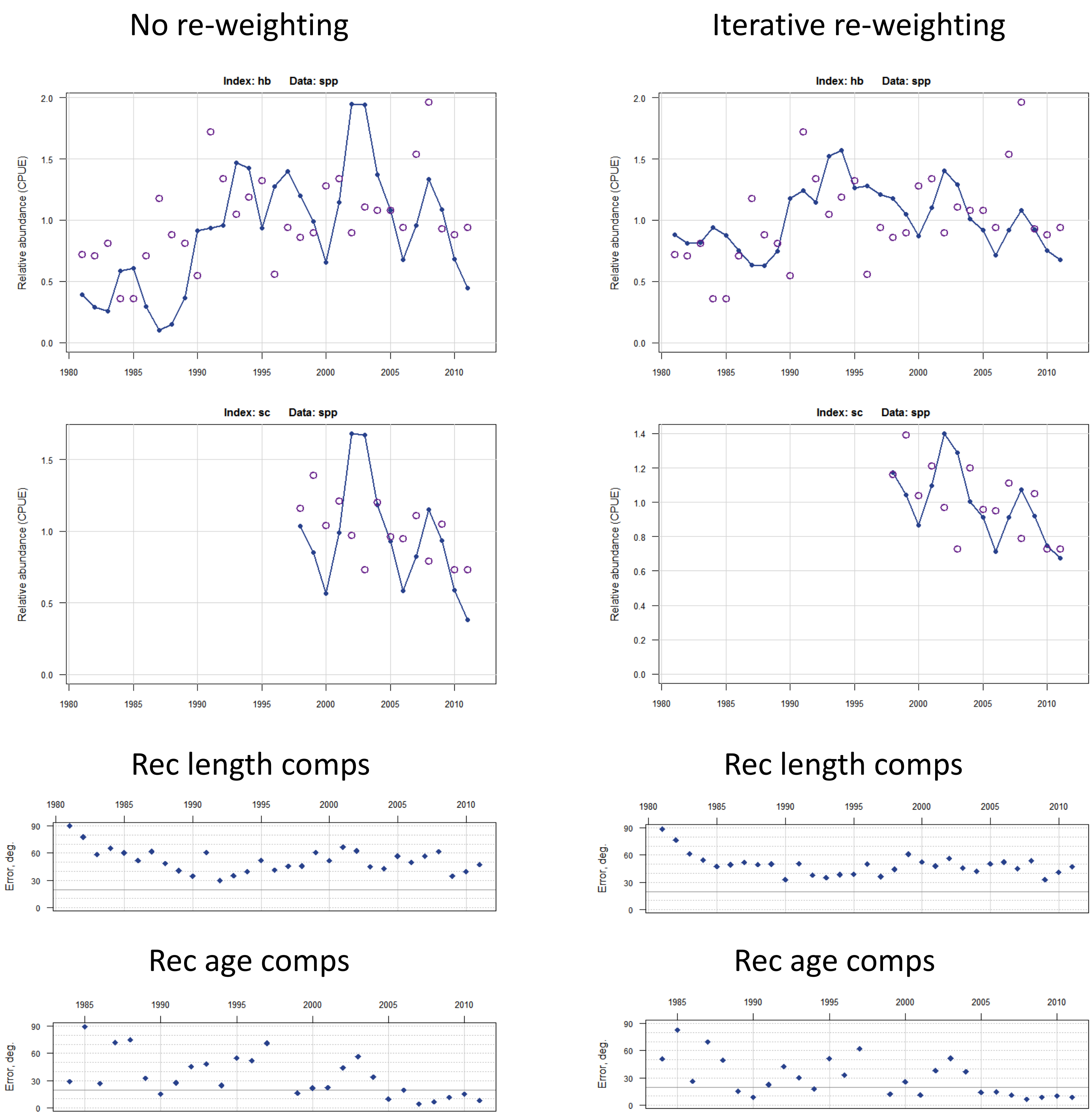


Figure 2. Final weights computed in model fits that did or did not account for potential correlations in the age composition and length composition data. Indices represented are Headboat (HB) and South Carolina logbook (SClog). Fisheries represented are the general recreational fleet (Rec length comps and Rec age comps). Weights for the general commercial fleet (not shown) were set equal to the corresponding weights for the recreational fleet.

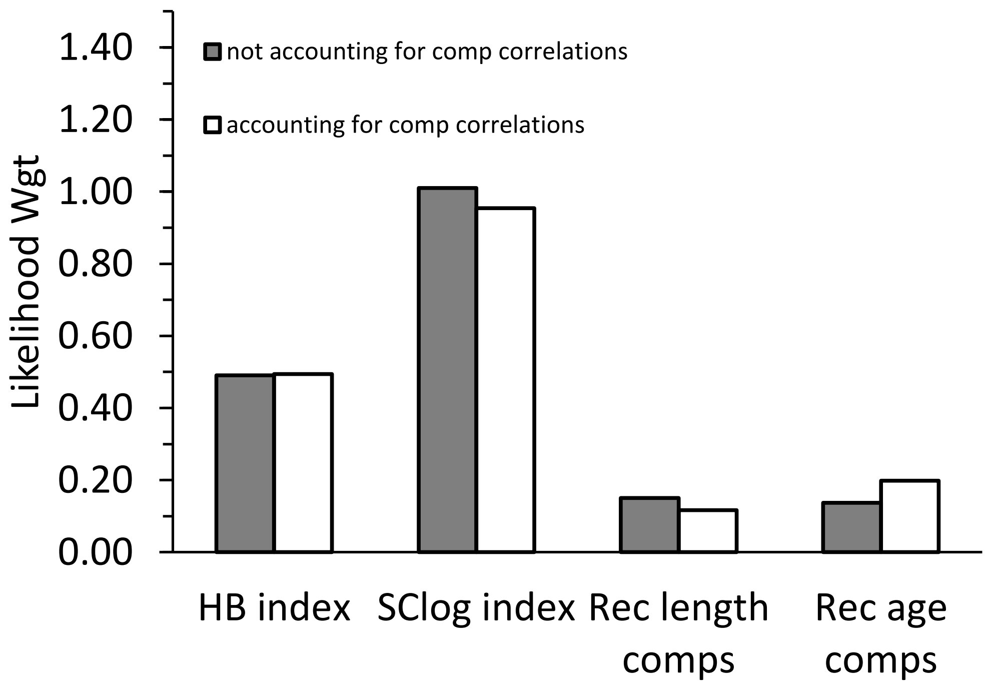


Figure 3. Likelihood weights from iterative re-weighting for sensitivity runs that included various combinations of indices (S13-S15 in the AW report). The four panels show the weights compared to the base run when only the headboat index (S13), the South Carolina logbook index (S14), or all three indices (headboat, South Carolina logbook, and MRFSS; S15) were included.

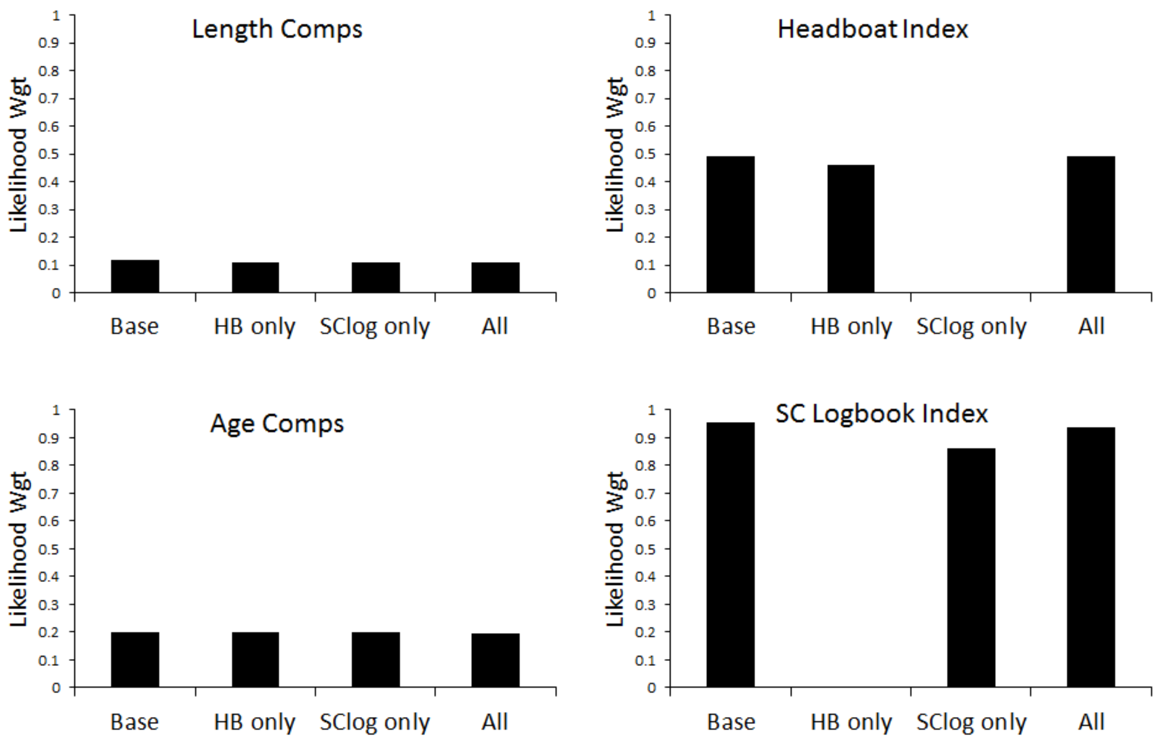


Figure 4. Standardized proportions at year (SPAY) plots. Light gray indicates above average proportion at age, black indicates below average proportion at age. The size of bubbles within each data set is scaled to the largest values. As indicated above the panels, spay plots are shown for predicted abundance, as well as for observed and predicted catches from fleets with suitably long time series of catch at age.

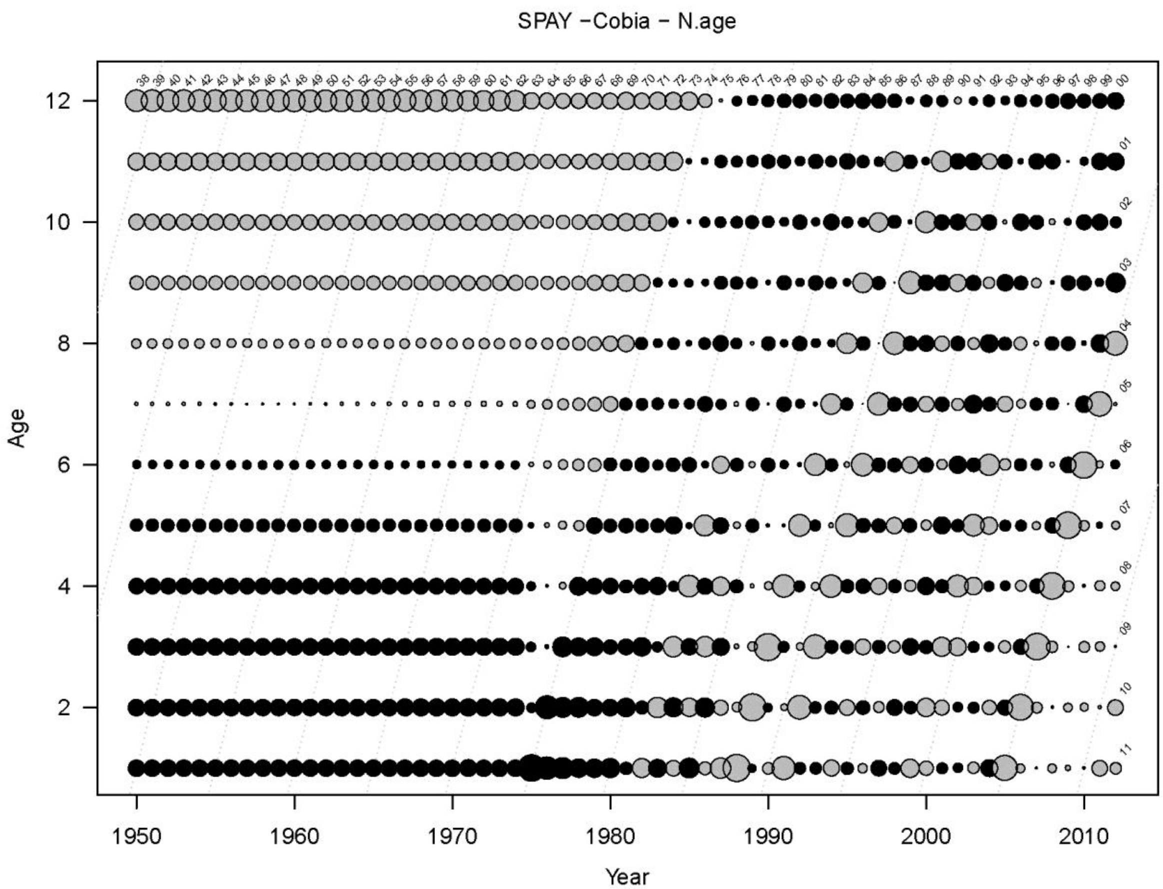
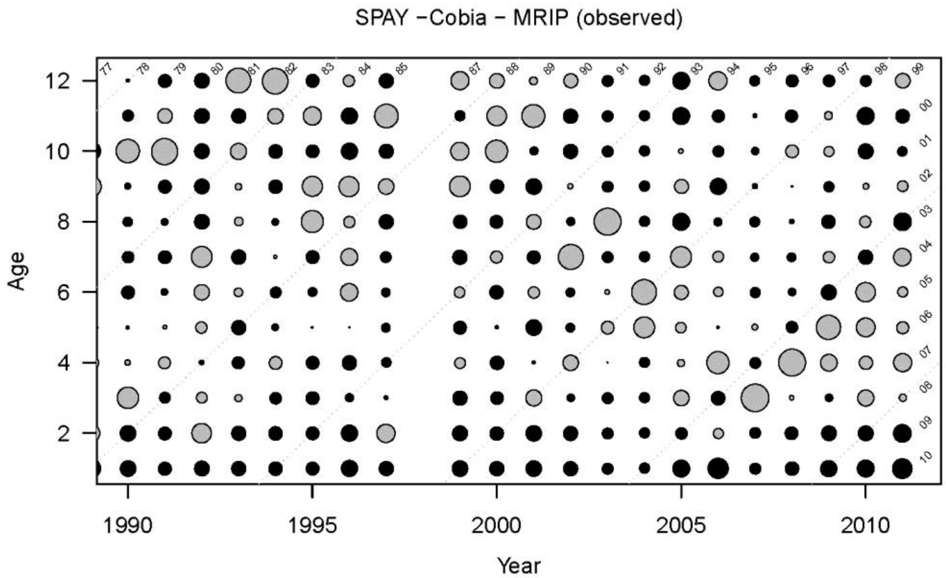


Figure 4 (cont.)



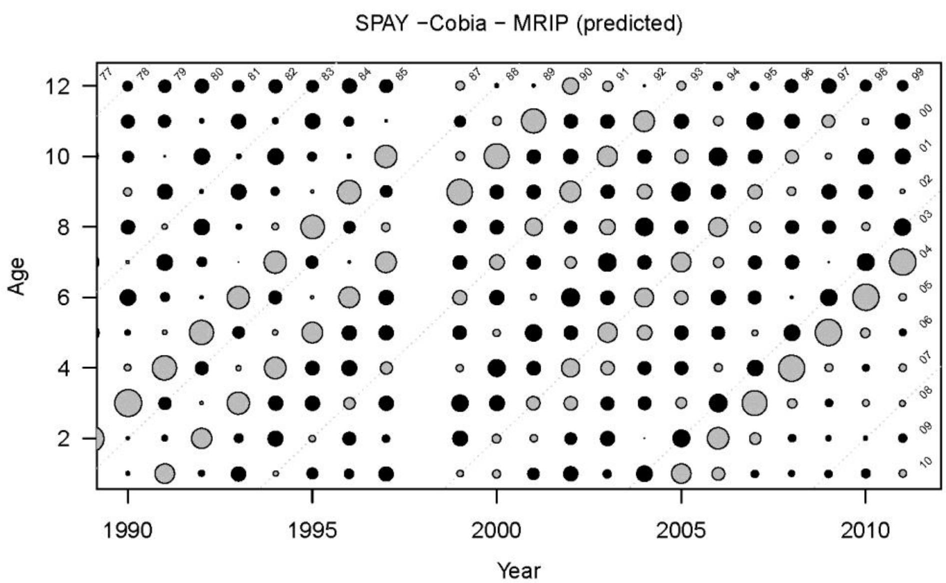
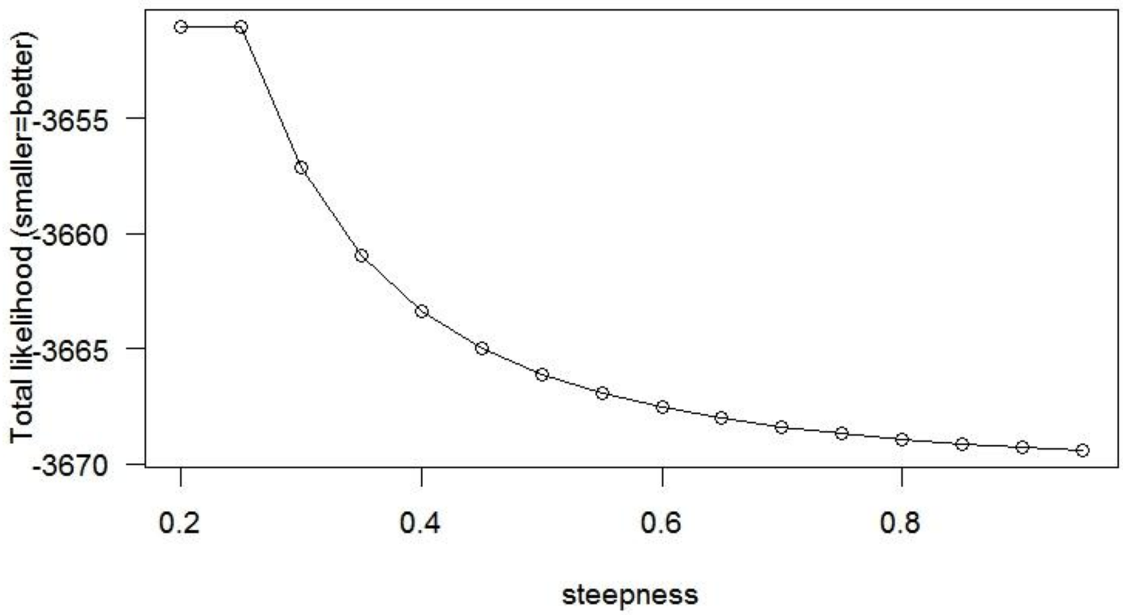


Figure 5. Likelihood profiles on steepness and R0.



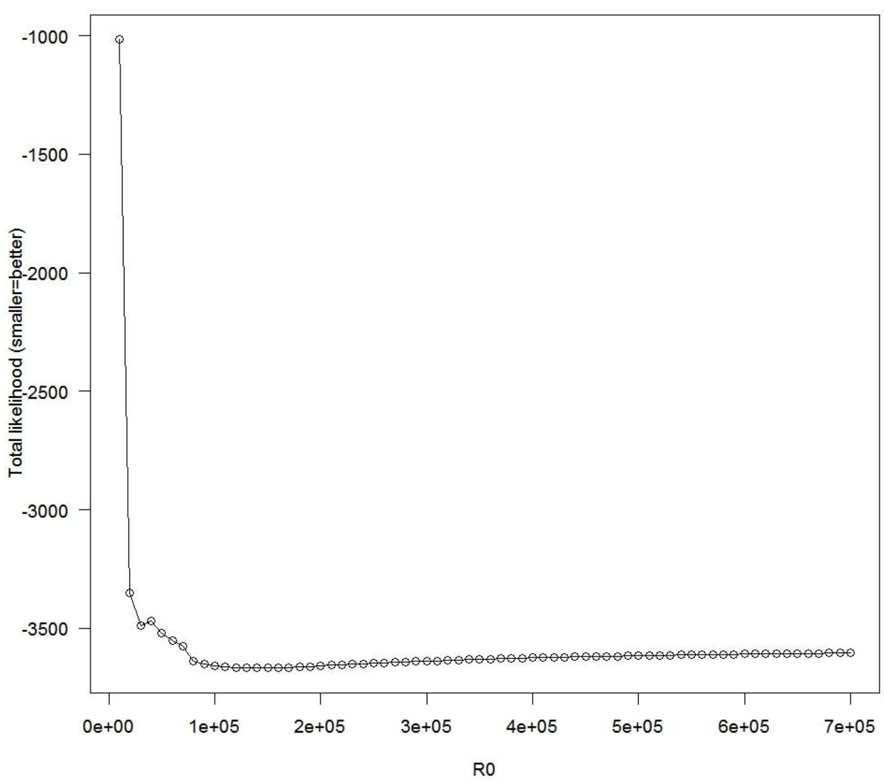
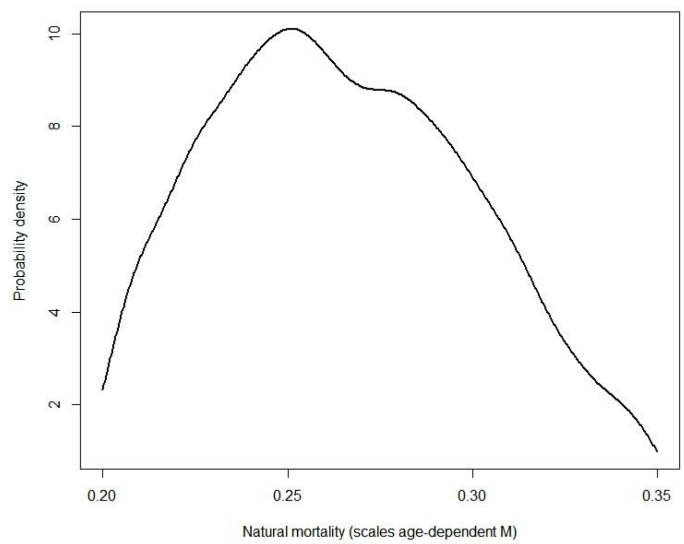


Figure 6. Distributions of parameters subjected to variability during the mixed Monte Carlo and bootstrap procedure. These parameters include natural mortality, steepness, and a multiplier on historical recreational recreational landings.



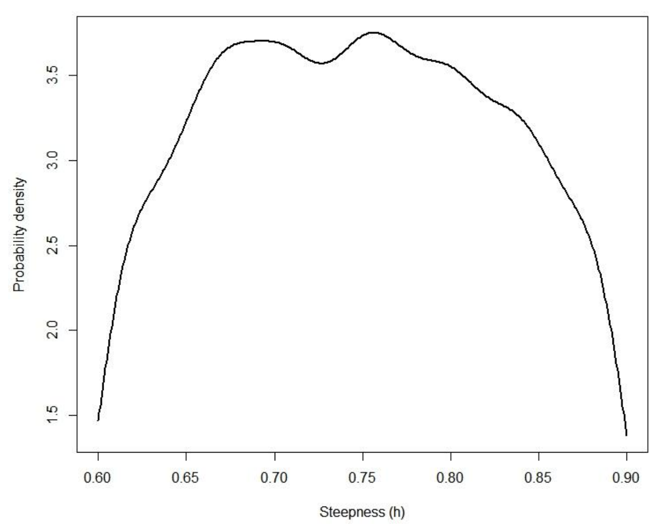


Figure 6 (cont.)

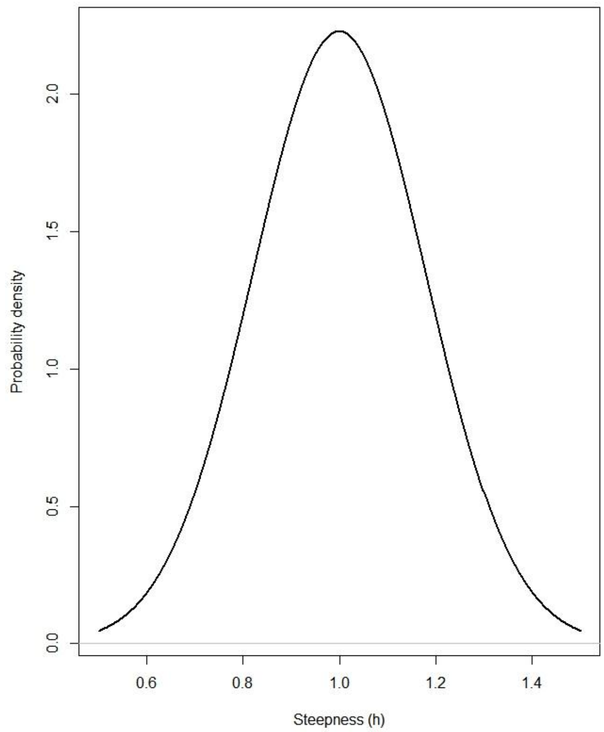


Figure 7. Standard errors of management quantities as a function of the number of Monte Carlo/bootstrap iterations.

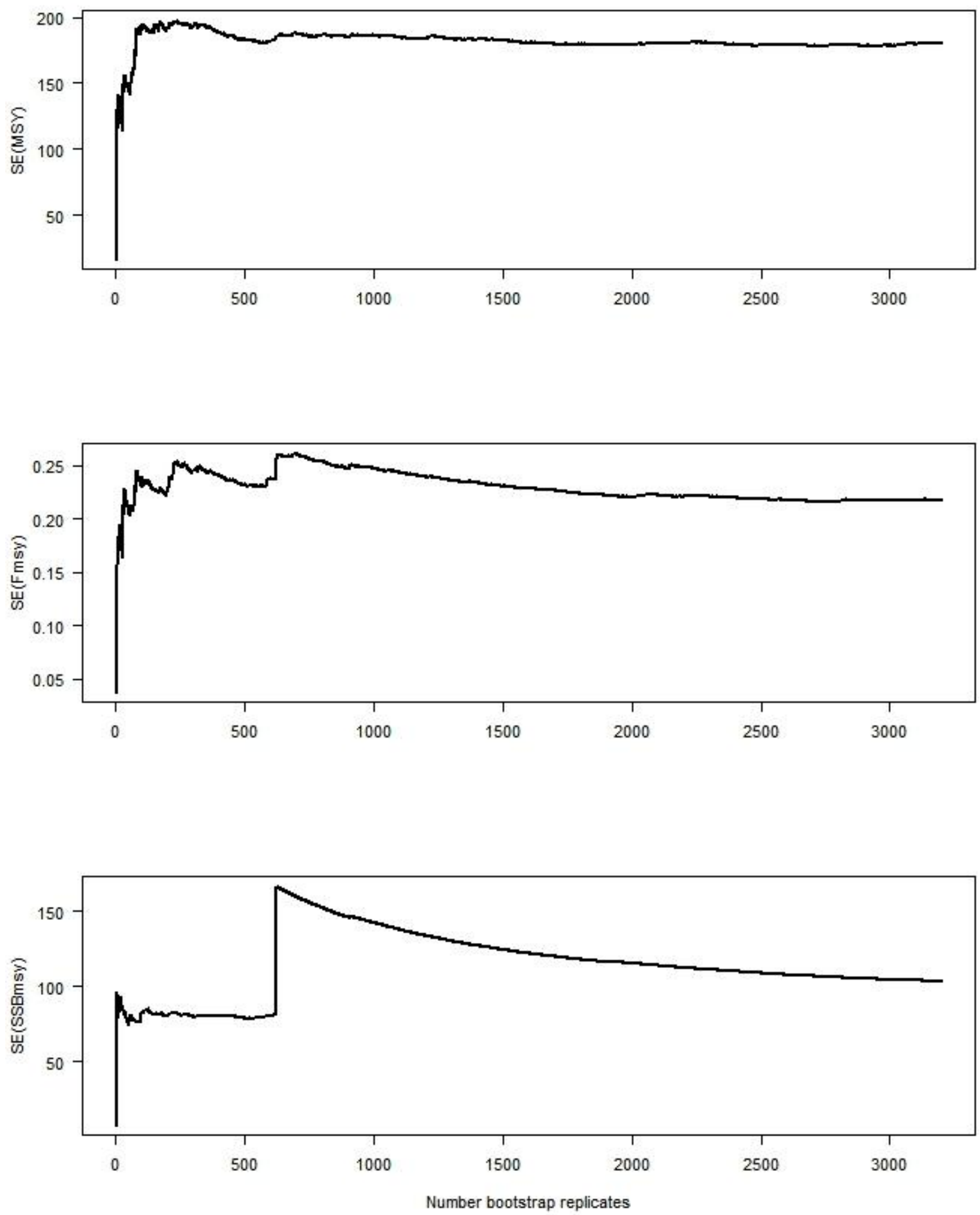


Figure 8. Catch curve analysis of recreational age composition data (synthetic cohorts) using the method of Thorson and Prager (2011). F calculated as F=Z-M where M=0.26. F could not be estimated for three years (2007-2009).

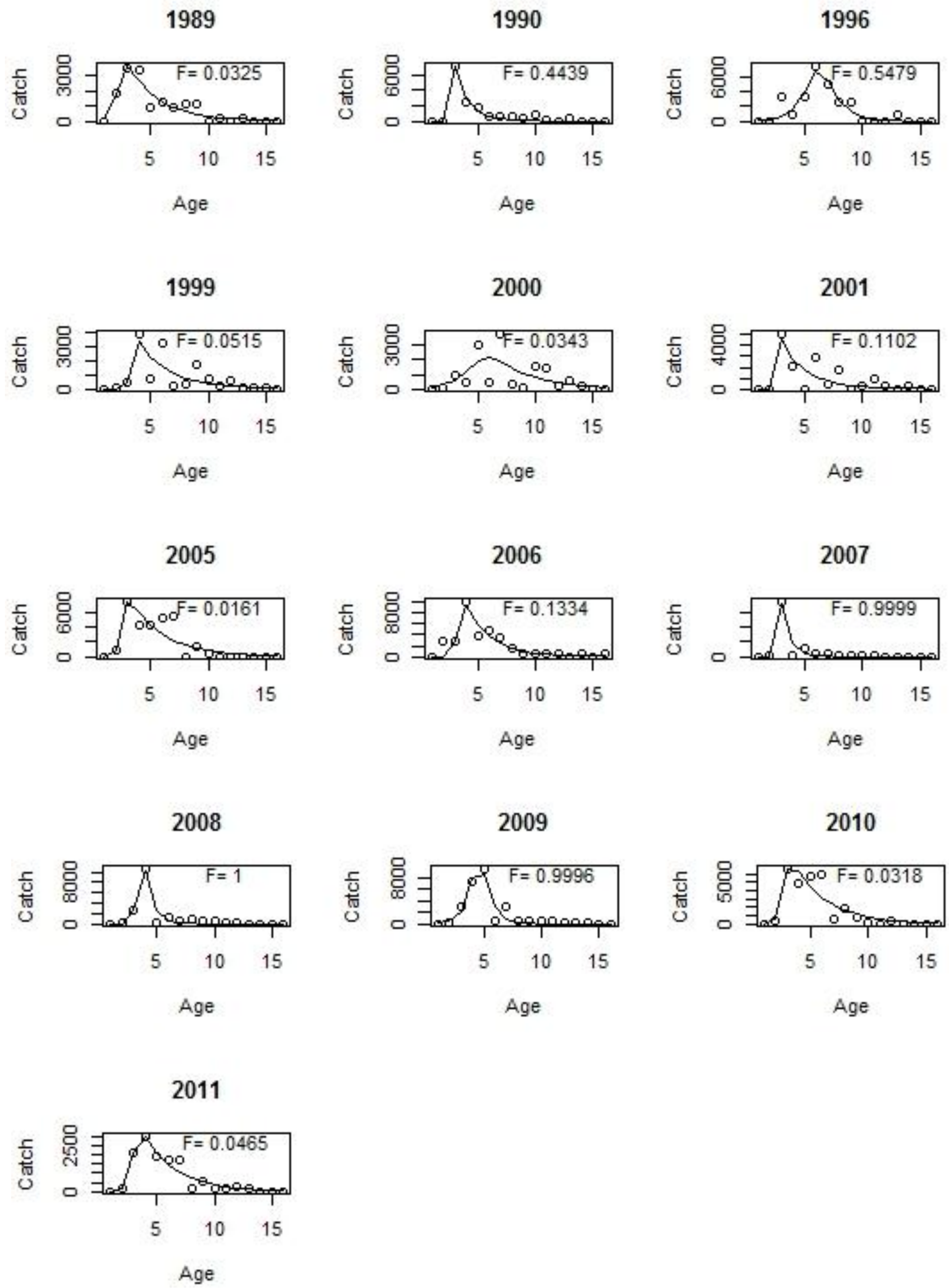


Figure 9. Annual selectivities estimated from catch curve analysis of recreational age composition data (synthetic cohorts) using the method of Thorson and Prager (2011).