Update of the Gulf of Mexico King Mackerel Base Assessment Model, Based on SEDAR-16 Recommendations

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Introduction

The Virtual Population Analysis (VPA) results described in this document provide an update of the base model for the Gulf king mackerel assessment following the recommendations from the review panel of the SEDAR-16 Review Workshop (Ref Report RW[1]). Referring to the fishery-independent SEAMAP Fall Groundfish index that was used initially for the assessment, the review panel concluded that "the use of lowest observations to replace zero observations under assumption of a lognormal distribution was erroneous. The RW requested that the GOM base case be corrected to take this into account" (SEDAR 16 South Atlantic and Gulf of Mexico King mackerel. Section V: Review Workshop Report 2008). This document presents the complete results of the VPA for the updated base case GOM following the RW request. We refer to this update as the "Final model".

For completeness, this document presents the inputs and general assumptions of the Final model. These are the same as in the base model presented in SEDAR16-RW-01, except for the Fall Groundfish index (see below). Model settings and inputs as decided by the Assessment and Review Workshops are summarized in Table 1. The VPA model assumed that fish caught in the mixing zone during winter (Nov-Mar) represents a 50% mix of Atlantic and GOM king mackerel, therefore landings and dead discards from this area were split equally between stocks. The VPA model also estimated all terminal-F (fishing mortality) parameters except the plus group, which was assumed to be equal to the prior age class for all years in the assessment evaluation (1981-2006). The model fits a selectivity pattern by age for each index that is constant over time (Butterworth and Geromont 1999 formulation) estimated from the partial catch at age associated with each index of abundance. The VPA model equally weighted relative indices of abundance while preserving inter annual variations, by fixing the variance scaling parameters to the values presented in Table 2. No recruitment patch was applied in the Final. Tables 3 and 4 summarize the biological parameter inputs for the GOM Final model, while Table 5 shows the catch at age matrix input including landings and dead discards. Average proportions of dead discards by age from the last three years (2004-06) were used for projections of stock status to estimate landings only (same time period used for estimate average selectivity of current fisheries for projection purposes). Relative indices of abundance are shown in Table 6. Note that for the SEAMAP Fall Groundfish index, the first three values (years 1981-1983) were removed as per the recommendation from the review panel. The partial catches at age associated with each index are the same as those presented in Table 3.28 of the SEDAR16-RW-01 document. A penalty was used for to constrain changes in selectivity during the most recent three years. The penalty was applied to ages 3-9 (SD=0.4).

The parameters estimated by the VPA were the terminal-F values for ages 0 to 10 and a catchability coefficient for each index. Initial guess estimates of terminal-F were set a 0.15 for ages 0 to 10. Uncertainty in model fit was evaluated by running 1000 non-parametric bootstraps of the index residuals. From these bootstraps, estimates of central tendency (median and average), bias and variance (standard error, coefficient of variation, and 80% confidence limits) were calculated for estimated parameters and derived stock indicators such stock size, biomass, fishing mortality, recruitment and yields.

Following decisions by the SEDAR 16 assessment and review panels, benchmarks for the king mackerel GOM stock unit were calculated as follows:

- F_{MSY}: estimated by the proxy $F_{30\%SPR}$.

[1] Available from http://www.sefsc.noaa.gov/sedar/

- B_{MSY}: estimated by the equilibrium SSB resulting from fishing at $F_{30\%SPR}$ and assuming the equilibrium stock-recruitment relationship adopted (see paragraph below).
- MSY: estimated by the equilibrium yield resulting from fishing at $F_{30\%SPR}$ and assuming the equilibrium stock-recruitment relationship adopted.

The following treatments of the data and assumptions were used in making the corresponding calculations: Current F ($F_{current}$) vector at age was calculated from the geometric mean of the age-specific F values for the most recent three years (2004-06). In this document, when a single value is used for $F_{current}$ it refers to the highest value in the vector. Current selectivity was computed by re-scaling the $F_{current}$ vector to a maximum value of 1. Spawning stock biomass (SSB) was computed as the product of the numbers at age at the beginning of each year, times the maturity at age, times fecundity (hydrated eggs per female) at age. Thus SSB reflects egg production. The expected spawner-recruitment relationship adopted assumed a Beverton-Holt function with a steepness of 0.95 (i.e. recruitment is nearly constant at most levels of SSB) and a maximum expected recruitment equal to the geometric mean of VPA estimated recruits over the years for which indices of stock and recruitment abundance were both available (1981-2004).

Projections of stock status for FY2007-2016 (FY = fishing year) were performed under different scenarios of fishing mortality or constant catch using the same assumptions as the calculations of benchmarks. In all cases, projection scenarios began in FY2008. FY2007 was assumed to be equal to the 2006 Fcurrent estimate (see previous paragraph). Projections were run using the projection software PRO-2BOX (Porch, 2002b). To estimate the variance of the projections, 1000 VPA bootstraps were projected for each scenario, allowing lognormal random variation of the assumed stock-recruitment relationship. The variance for the stock-recruitment relationship was estimated from the deterministic VPA stock-recruitment fit.

Results

Measures of overall model fit

The model fit was assessed using the objective function, likelihood statistics (Table 7) and fits to the indices of abundance (Fig 3). AIC, AICC and BIC values are also summarized in Table 7, but these are not directly comparable between models with different number of observations and parameters. For comparison equivalent values are presented for the base model. The overall objective function is lower in the Final model; however the Final model has only 103 observations, compared to the base model with 106 (recall that the deletion of the first 3 years of the SEAMAP Groundfish index is the difference between the models). Overall fits of indices of abundance followed same trends between the Base and Final models, with the exception of the SEAMAP Groundfish fit which indicated higher catch rates particularly in the early years after the exclusion of the 1981/84 observations (Fig 3). Figure 4 shows the normalized cumulative residual plots or qq-plots of the Final model. Note that the q-q plots suggest that there may continue to be some outliers, particularly for the two fishery-independent indices. Overall, the final model fits continue to estimate increasing abundance, particularly in the most recent years. This result is supported by the fishery- independent indices, but such trend is not shown by the fishery dependent indices. Because of conflict in the trends of several indices, the choice of index weighting in the VPA continues to have a substantial impact on the results of the final model, as it did for the base case.

Parameter estimates and associated measures of uncertainty

Parameter estimates and the associated maximum likelihood estimate (MLE), bootstrap average, bias, standard error and coefficient of variation (CV) are summarized in Table 8. Coefficients of variation ranged from 19% to 37% for the terminal fishing mortality rates by age, being higher for ages 0 and 1.

Stock abundance and Recruitment

Annual estimates of stock size from the final model are tabulated in Table 9, while estimates of spawning stock (in millions of hydrated eggs) and recruitment are tabulated in Table 10 for the deterministic run. Figure 5 shows the annual trends of total biomass, spawning biomass, stock size, recruits, apical fishing mortality, and yields with estimated 80% confidence limits (broken lines) around the median value (red line) of 1000 bootstrap runs. For comparison purposes, the median value of the GOM base case is also plotted (blue line). The largest differences between the base and Final models are in the estimates of total biomass, stock size and recruits in the last 5-6 years. The Final model estimated lower numbers of recruits since 1996. That translated to lower stock size and stock biomass (also spawning stock) after 2001. As removals (yields) were the same, lower stock size estimates were compensated with higher fishing mortality rates in the latest years.

Overall trends for the Gulf stock indicated a recovery from lower stock size in the early 1980's up to late 1990's. Simultaneously, the final model estimated large recruitments during those years, which increased the stock size and spawning stock biomass to the highest levels observed in 2006, roughly twice the biomass of 1981. During recent years, recruitment has been quite high, averaging 15 million fish since 2003. These large recruitment estimates are driven by the steep increase in the SEAMAP Groundfish Survey which indexes the abundance of age-0 king mackerel and has increased more than 5-fold since the early 1980s. Spawning stock trajectories, as a function of the status determination criterion MSST are shown in Fig 2. In the Gulf of Mexico, spawning stock has increased since the early 1980's when it was below MSST (0.57 in 1985) to be above 1 since 1999. In 2006 SSB was estimated to be 1.5 times MSST (Table 10).

Fishing mortality and selectivity

Annual estimates of fishing mortality at age are tabulated in Table 11 for the deterministic run. Figure 1 shows the annual fishing mortality trends expressed as $F_{current}$ (highest value of the geometric mean by age of the current year and the prior 2 years, thus starting in 1983). Table 12 summarizes the estimates of apical F (highest fishing mortality from the FAA vector by year), $F_{current}$, and the ratio of $F_{current}$ over MFMT. In the Gulf, fishing mortality increased from 1981 to a peak in 1995 followed by a decreased since that time. Compared to MFMT, fishing rates were above MFMT from 1981 until 2001. Since 2002, fishing mortality has been below MFMT and in 2005, it was estimated to be 83% of MFMT.
Fleet-index selectivity at age was estimated using the partial catches (fleet specific catch-at-age) and assuming the Butterworth and Geromont (1999) method that computes an average, constant selectivity pattern for the entire time period. The shrimp bycatch index and fleet were assigned a fixed selectivity equal to 1 for age 0 only, while the SEAMAP plankton survey was used to index spawning stock biomass, and assigned a fixed selectivity equal to the maturity*fecundity at age vector. Table 13 shows the estimated selectivity by age of the GOM Final model. For the commercial fisheries, maximum selectivity corresponds to age 8, but for ages 3 and older selectivity is above 0.5 (Fig 6). For the recreational fisheries, maximum selectivity corresponded to ages 3 (MRFSS) and 2 (Headboat). At older ages, the recreational headboat fishery has a lower selectivity than the commercial and MRFSS fisheries.

Stock status

According to the deterministic results of the final model, the Gulf migratory stock was not overfished nor was overfishing occurring in 2006 (Table 14). Following the recommendations of the review panel, for status report fishing mortality was expressed as the highest value of the geometric mean of last three years (2004-06) for ages 2 through 8 only, as they represent the main ages of the directed fisheries for king mackerel stocks. Figure 7 shows the status or phase plot for FY2006. The deterministic result indicates that fishing mortality was 83% of MFMT while the spawning stock was 1.5 times greater than MSST. The results of 1000 bootstraps indicate the degree of uncertainty about the model fit. Figure 8 shows the histograms and cumulative distribution of the ratios of fishing mortality and spawning stock in 2006. Only 59 out 1001 (5.9%) runs resulted in $F_{current}$ > MFMT, and 3 out of 1001 (0.3%) runs resulted in SSB < MSST.

Retrospective analysis

Retrospective analyses of the GOM VPA Final model were performed by sequentially removing input data from FY2006 up to FY2001. Figure 9 summarizes the retrospective patterns of stock size (Total NAA), spawning stock, $F_{current}$, and stock size by age groups (Age 0, Age1-3, Age 4-7, Age 8-10, Age 11+). There was a pattern of over-estimating stock size and spawning biomass as new information become available; correspondingly there was a pattern of under-estimating fishing mortality rates. By age group, ages 4 and older show greater differences between the retrospective runs.

Table 1. Model settings and inputs used to construct the VPA Final model.

Settings/Input Series	VPA-2BOX GOM Final Model
Stock Definitions	Total catches calculated according to the 50:50 mixing zone assumption: **GOM stock** - US Gulf of Mexico from Texas to Collier County, FL during Apr - Oct and to Volusia County, FL during Nov- Mar.
Fishing Year	Like SEDAR5, catch and Indices estimated using "fishing year" definitions. July 1st to June 30th of following calendar year.
Directed Landings/Discards	Used updated SEDAR 16 landings estimates. For the recreational sector, used SEDAR 16 landings, discards and release mortality estimates. As per SEDAR 16 recommendation, commercial discards were assumed to be negligible.
Shrimp Bycatch	Used Delta Lognormal Shrimp Bycatch estimates (SEDAR16-AW-07).
Catch-at-age	For estimation of the CAA: updated growth von Bertalanffy parameters (SEDAR16-DW-06) by sex and stock using observations collected outside of the MIX area. CAS 2001-2006 updated, sex at size ratios updated from 1985 through 2006. ALK constructed by semester and used from 1984 to 2006, SAR only for 1981-84 years. Recreational CAA adjusted to meet SEDAR 16 Recreational panel recommendations.
Weight-at-Age	Updated vector of weight at age estimated from the age samples and the updated weight-at-size relationship by sex and stock from samples from non-mixing areas.
Indices of Abundance	Used indices consistent with the "updated" approached recommended by SEDAR 16 for SS3 and other updated model runs.
Natural Mortality	Used Lorenzen's M vector developed at SEDAR16 DW and AW workshops.
Terminal Year F-at-age	Estimating all Terminal F's for ages 0-11+ (GOM) with fixed ratio for last age class all years of 1 and using maximum likelihood estimation with lognormal error distribution for index variances.
Annual F-Ratio	For each year $F_{10} : F_{11+}$ was fixed at 1.0. This implies that the fishing mortality rate on the plus group is equal to the fishing mortality rate on age 10.

Table 2. Fixed variance scalars used to equally weight the relative indices of abundance for the GOM Final VPA model.

Index	Variance Scalar
COM_GULF_NOMIX	0.535411
MRFSS_GULF_NOMIX	0.441492
HEADBOAT_GULF_NOMIX	0.51837
SEAMAP_GROUNDFISH	0
SEAMAP_PLANKTON	0.464832

Table 3. Biological input parameters GOM king mackerel Final VPA model.

Age	Proportion Mature	Fecundity (millions of female eggs)	Natural Mortality
0	0.000	0.000	0.765
1	0.157	0.155	0.274
2	0.529	0.267	0.243
3	0.704	0.395	0.222
4	0.856	0.531	0.207
5	0.989	0.669	0.196
6	1.000	0.801	0.188
7	1.000	0.926	0.182
8	1.000	1.041	0.177
9	1.000	1.145	0.173
10	1.000	1.238	0.170
11+	1.000	1.524	0.162

Table 4. Weight at age (kg) matrix input GOM king mackerel Final VPA model.

Year	Age 0	Age 1	Age 2	Age 3	Age 4	Age 5	Age 6	Age 7	Age 8	Age 9	Age 10	Age 11
1981	0.424	1.857	2.817	3.825	4.825	6.005	7.062	8.125	8.942	10.023	10.786	12.835
1982	0.424	1.857	2.817	3.825	4.825	6.005	7.062	8.125	8.942	10.023	10.786	12.835
1983	0.424	1.857	2.817	3.825	4.825	6.005	7.062	8.125	8.942	10.023	10.786	12.835
1984	0.424	1.857	2.817	3.825	4.825	6.005	7.062	8.125	8.942	10.023	10.786	12.835
1985	0.424	1.857	2.817	3.825	4.825	6.005	7.062	8.125	8.942	10.023	10.786	12.835
1986	0.424	1.429	2.630	3.697	4.953	6.605	7.425	8.463	9.388	10.601	10.791	14.727
1987	0.424	1.429	2.630	3.697	4.953	6.605	7.425	8.463	9.388	10.601	10.791	14.727
1988	0.424	1.429	2.630	3.697	4.953	6.605	7.425	8.463	9.388	10.601	10.791	14.727
1989	0.424	1.429	2.630	3.697	4.953	6.605	7.425	8.463	9.388	10.601	10.791	14.727
1990	0.424	1.429	2.630	3.697	4.953	6.605	7.425	8.463	9.388	10.601	10.791	14.727
1991	0.424	1.787	2.868	3.902	5.233	6.426	7.759	8.628	9.079	10.085	11.175	12.155
1992	0.424	1.787	2.868	3.902	5.233	6.426	7.759	8.628	9.079	10.085	11.175	12.155
1993	0.424	1.787	2.868	3.902	5.233	6.426	7.759	8.628	9.079	10.085	11.175	12.155
1994	0.424	1.787	2.868	3.902	5.233	6.426	7.759	8.628	9.079	10.085	11.175	12.155
1995	0.424	1.787	2.868	3.902	5.233	6.426	7.759	8.628	9.079	10.085	11.175	12.155
1996	0.424	1.989	3.166	3.912	4.842	5.877	6.802	8.342	10.015	10.783	11.792	13.103
1997	0.424	1.989	3.166	3.912	4.842	5.877	6.802	8.342	10.015	10.783	11.792	13.103
1998	0.424	1.989	3.166	3.912	4.842	5.877	6.802	8.342	10.015	10.783	11.792	13.103
1999	0.424	1.989	3.166	3.912	4.842	5.877	6.802	8.342	10.015	10.783	11.792	13.103
2000	0.424	1.989	3.166	3.912	4.842	5.877	6.802	8.342	10.015	10.783	11.792	13.103
2001	0.424	2.205	2.700	3.752	4.515	5.644	6.383	7.465	8.311	8.954	9.835	11.276
2002	0.424	2.205	2.700	3.752	4.515	5.644	6.383	7.465	8.311	8.954	9.835	11.276
2003	0.424	2.205	2.700	3.752	4.515	5.644	6.383	7.465	8.311	8.954	9.835	11.276
2004	0.424	2.205	2.700	3.752	4.515	5.644	6.383	7.465	8.311	8.954	9.835	11.276
2005	0.424	2.205	2.700	3.752	4.515	5.644	6.383	7.465	8.311	8.954	9.835	11.276
2006	0.424	1.857	2.817	3.825	4.825	6.005	7.062	8.125	8.942	10.023	10.786	12.835

Table 5. Catch at age matrix for the GOM king mackerel VPA input model. Values represent numbers of total removals (landings plus dead discards) by age and fishing year.

YEAR	AGE 0	AGE 1	AGE 2	AGE 3	AGE 4	AGE 5	AGE 6	AGE 7	AGE 8	AGE 9	AGE 10	AGE 11+
1981	563558	16502	32123	216871	193314	48635	27492	21808	9186	3956	4478	14377
1982	243454	54716	180776	153648	207284	149504	65765	17918	17540	20438	6619	175346
1983	476064	91748	189468	105003	26340	44481	30319	6440	9090	4724	1493	16195
1984	1508666	20567	57951	220927	127844	36116	49028	25614	4755	918	1861	17130
1985	732206	23940	56050	94130	72300	83910	31470	12844	18712	4959	1902	17167
1986	815006	36703	209494	80517	34943	54577	39512	12383	2971	6846	575	14812
1987	1477266	99255	77574	32265	25616	29870	16917	8010	4597	3468	2208	6704
1988	1695068	46813	97259	88300	64139	31361	68867	29739	6050	13561	13274	33536
1989	2743625	122445	163030	81732	70834	52482	12200	22971	10889	4445	6203	16935
1990	2093282	104655	163800	105030	73158	35254	37946	7373	18872	8489	1626	18612
1991	2019187	182252	240676	127600	70578	39801	27502	12904	4475	19490	5126	12161
1992	1466838	65491	200838	182078	103020	54354	47024	21010	34006	9313	16888	24785
1993	2812413	60138	146028	151588	134914	62068	36287	25513	24429	13000	1661	34235
1994	3138105	126336	154850	124591	162044	117838	68954	41251	24627	19865	39629	33969
1995	2742216	47871	174393	162710	103136	64878	67180	31299	17621	7851	10630	16723
1996	1376113	87094	242333	156665	86928	53091	35928	35028	27723	12873	2794	41110
1997	1348322	54227	153386	203561	103652	71213	45217	45932	29291	21473	8579	28477
1998	1193085	58339	118231	153169	168698	71258	39946	24472	17403	20184	9092	7159
1999	1210741	45716	127966	94029	116636	88794	28844	27385	19486	22445	3109	11011
2000	1078106	64037	134236	175846	98004	63813	28820	33574	8830	14003	10681	17482
2001	772155	48512	145760	146855	117572	69132	47701	42979	25854	7766	6992	28300
2002	641205	70633	204402	130239	112020	73224	39778	30365	30256	15391	7387	21823
2003	1542801	27247	151935	158851	96919	67925	58810	25398	25196	17727	15759	17722
2004	2888086	33563	230128	129788	105691	54044	42874	37388	10928	22677	6758	14034
2005	1909290	23552	164254	175586	122746	76873	52471	41831	29796	11442	10628	27227
2006	923292	20093	178244	203485	158511	107711	58659	42905	28343	16720	8995	28893

Table 6. Updated relative indices of abundance and index settings used for the GOM Final VPA model.

	Com Logboof Gulf-No		MRFSS-Gulf-No-Mix		HB-Gulf-no-Mix		SEAMAP Fall Groundfish		SEAMAP Fall Plankton	
Type of Index	Fish. Dep. REC		Fish. Dep. REC		Fish. Dep. REC		Fish. Independent		Fish. Independent	
Unit	Biomass		Number		Number		Numbers		Numbers	
Likely Applies to Ages	Ages 1-11+		Ages 1-11+		Ages 1-11+		Age 0		Ages 1 to 11+, using partial selection	
YEAR	STDCPUE	CV	STDCPUE	CV	STDCPUE	CV	STDCPUE	CV	STDCPUE	CV
1981	-	-	0.722	0.424	-	-	-	-	-	-
1982	-	-	0.467	0.407	-	-	-	-	-	-
1983	-	-	0.883	0.428	-	-	-	-	-	-
1984	-	-	0.501	0.390	-	-	0.101	0.911	-	-
1985	-	-	0.550	0.417	-	-	0.045	0.823	-	-
1986	-	-	0.451	0.338	0.677	0.184	0.085	1.080	0.116	0.534
1987	-	-	1.077	0.303	0.699	0.175	0.018	1.482	0.379	0.322
1988	-	-	0.710	0.324	0.809	0.194	0.122	0.527	0.613	0.437
1989	-	-	0.923	0.332	0.799	0.186	0.101	0.702	0.845	0.326
1990	-	-	1.292	0.318	0.558	0.170	0.162	0.409	0.648	0.321
1991	-	-	1.263	0.301	1.371	0.156	0.063	0.565	0.721	0.318
1992	-	-	1.002	0.293	1.234	0.153	0.096	0.559	0.596	0.237
1993	0.720	0.132	0.998	0.301	0.838	0.151	0.424	0.325	1.251	0.199
1994	0.881	0.101	1.243	0.290	1.205	0.133	0.183	0.480	1.050	0.231
1995	0.990	0.093	1.115	0.305	1.295	0.134	0.108	0.641	1.979	0.195
1996	0.974	0.078	1.322	0.299	1.437	0.142	0.087	0.532	0.741	0.265
1997	1.307	0.069	1.480	0.285	1.307	0.140	0.209	0.425	1.360	0.201
1998	1.288	0.068	1.083	0.286	1.084	0.145	0.224	0.413		
1999	1.118	0.065	0.922	0.281	1.286	0.150	0.177	0.396	0.920	0.225
2000	1.068	0.062	1.213	0.276	0.890	0.153	0.202	0.480	0.922	0.273
2001	1.055	0.064	1.114	0.280	0.686	0.160	0.252	0.376	1.642	0.203
2002	0.994	0.061	1.239	0.276	0.729	0.150	0.144	0.536	1.451	0.214
2003	0.985	0.069	0.967	0.282	1.055	0.153	0.566	0.289	1.103	0.219
2004	0.923	0.073	1.019	0.281	0.654	0.162	0.450	0.308	1.478	0.211
2005	0.732	0.093	0.860	0.290	1.038	0.163	0.491	0.292		
2006	0.966	0.083	1.584	0.276	1.351	0.149	0.381	0.369	1.187	0.253

Table 7. Likelihood statistics comparison for GOM king mackerel VPA Final and base models. Loglikelihood measures of model fits to the indices of abundance and associated information criteria. Note that the number of observations between models differs.

Model	Final Model	Base Model
Total Objective Function	-46.26	-35.54
with constants	48.39	61.87
Number of parameters	16	16
Number of data points	103	106
AIC	128.78	155.74
AICC	135.11	161.86
BIC	170.94	198.36
Chi-square discrepancy	44.41	57.18
Loglikelihoods (Deviance)	38.37	27.3
effort data	38.37	27.3
Constrains	7.89	8.23
Terminal F	7.89	8.23
Stock-re/ sex ratio	0	0
Out of bounds penalty	0	0
Log Likelihood Indices of abundance	38.37	27.31
Comm_Gulf No Mix	7.31	6.79
MRFSS Gulf No Mix	12.69	11.69
Headboat Gulf No Mix	9.59	8.33
SEAMAP Groundfish	3.38	-4.77
SEAMAP Plankton	5.4	5.24

Table 8. Final values for estimated parameters of the GOM VPA Final model, estimates of variance based on one thousand non-parametric bootstraps of the index residuals.

Final VPA GOM Model

Terminal Age structure of population abundance

Age	MLE	Avg of booststraps	Bias	Std error	% CV
1	5640000	6290000	995000	3070000	48.8
2	4900000	4970000	1280000	1990000	40.1
3	4350000	4990000	249000	1140000	22.9
4	1600000	1360000	141000	409000	30.1
5	614000	706000	41000	162000	23
6	323000	373000	22600	85300	22.9
7	159000	228000	-6180	51400	22.6
8	142000	158000	-2520	36800	23.2
9	145000	135000	2470	37600	28
10	160000	133000	11000	39100	29.5
11+	383000	268000	39300	95200	35.6

Terminal Age structure of fishing mortality rate

Age	MLE	Avg of booststraps	Bias	Std error	% CV
0	0.103	0.109	0.0000173	0.04	36.7
1	0.00356	0.00399	-0.00073	0.00131	32.8
2	0.0355	0.0325	-0.000172	0.00667	20.5
3	0.107	0.135	-0.00409	0.0355	26.4
4	0.208	0.191	-0.00251	0.0385	20.1
5	0.263	0.241	-0.0041	0.0464	19.3
6	0.287	0.219	0.014	0.0458	20.9
7	0.243	0.229	0.0119	0.0442	19.3
8	0.164	0.187	0.00857	0.0483	25.8
9	0.0911	0.117	-0.00125	0.0311	26.5
10	0.087	0.134	-0.00736	0.0403	30
11+	0.087	0.134	-0.00736	0.0403	30

Estimates of catchability by index

Index	MLE	Avg of booststraps	Bias	Std error	% CV
Com no Mix	5.33E-08	6.03E-08	-3.55E-09	6.94E-09	11.5
MRFSS	1.87E-07	2.04E-07	-1.24E-08	1.85E-08	9.1
Headboat	2.69E-07	2.80E-07	-1.83E-08	2.32E-08	8.3
SEAMAP Ground	2.77E-07	2.59E-07	-4.20E-08	3.06E-08	11.8
SEAMAP Plankton	4.68E-07	4.97E-07	-5.52E-08	6.04E-08	12.2

Table 9. Numbers at age for the GOM VPA Final model.

	Age 0	Age 1	Age 2	Age 3	Age 4	Age 5	Age 6	Age 7	Age 8	Age 9	Age 10	Age 11+
1981	4,487,847	1,326,649	861,939	1,012,106	737,795	189,395	120,981	101,667	75,034	27,830	151,474	484,493
1982	4,004,816	1,718,063	994,313	647,790	617,960	426,782	111,854	75,357	64,959	54,490	19,795	522,568
1983	1,962,239	1,702,742	1,258,719	620,999	382,417	317,248	216,456	33,816	46,564	38,475	27,253	294,514
1984	6,391,395	604,344	1,214,959	820,621	403,992	287,193	220,550	151,849	22,342	30,735	28,046	257,191
1985	4,472,095	1,994,897	441,621	901,928	461,274	214,185	203,392	138,359	103,319	14,390	25,013	224,921
1986	3,719,424	1,601,811	1,495,910	297,061	638,561	310,112	100,747	139,991	103,663	69,518	7,592	194,849
1987	5,267,802	1,200,690	1,185,966	989,007	166,502	487,667	205,611	47,866	105,442	84,143	52,216	157,947
1988	7,694,286	1,497,823	826,800	861,890	763,392	112,368	373,735	154,996	32,627	84,149	67,604	170,180
1989	8,987,466	2,478,087	1,098,133	562,895	611,683	562,929	64,123	247,268	102,206	21,825	58,396	158,840
1990	8,467,824	2,417,308	1,777,787	717,915	378,114	433,635	415,171	42,078	185,246	75,701	14,301	163,097
1991	6,431,419	2,583,534	1,747,014	1,250,171	481,547	241,798	324,481	309,537	28,381	137,992	55,916	132,164
1992	5,865,852	1,695,455	1,806,143	1,158,514	887,671	328,121	162,793	243,875	246,317	19,700	98,265	143,690
1993	9,795,834	1,779,149	1,232,179	1,239,851	765,914	629,089	220,600	92,386	184,200	175,371	8,127	166,899
1994	10,506,494	2,744,740	1,300,452	837,926	858,086	501,636	460,885	149,889	53,888	132,056	135,624	115,843
1995	9,132,397	2,868,587	1,977,142	883,712	560,265	552,282	306,086	319,348	87,556	22,861	92,933	145,662
1996	6,115,982	2,484,441	2,139,385	1,397,203	563,137	362,978	395,252	192,793	237,764	57,312	12,086	177,187
1997	7,689,198	1,951,572	1,813,284	1,464,707	979,570	379,788	250,364	294,865	128,906	173,926	36,465	120,607
1998	6,440,792	2,696,715	1,436,676	1,287,173	991,976	703,203	247,881	166,470	204,077	81,343	126,673	99,371
1999	5,795,505	2,218,106	1,999,622	1,022,737	894,578	655,086	513,488	169,173	116,538	155,105	50,018	176,486
2000	5,632,798	1,908,428	1,646,700	1,455,704	735,391	622,509	458,163	399,235	116,150	79,884	109,962	179,312
2001	5,702,963	1,917,670	1,395,362	1,173,375	1,009,375	509,835	453,904	353,422	302,290	89,258	54,409	219,408
2002	6,593,401	2,146,941	1,415,859	966,131	809,066	714,954	356,554	332,788	255,560	229,681	67,978	200,082
2003	10,790,938	2,645,720	1,570,975	930,713	657,890	557,157	521,369	259,325	249,815	186,526	179,119	200,684
2004	20,369,976	4,009,460	1,987,859	1,098,422	604,167	447,836	396,512	378,613	193,091	186,322	140,688	291,068
2005	16,600,606	7,584,351	3,019,205	1,356,615	764,213	396,355	319,209	289,619	281,633	151,806	135,999	347,110
2006	13,425,502	6,469,070	5,745,916	2,223,468	930,270	511,124	256,400	216,922	203,424	208,785	117,227	375,148
2007		5,637,706	4,900,951	4,349,990	1,599,606	614,064	322,949	159,352	141,878	144,598	160,330	383,127

Table 10. Trends of Spawning stock (millions of eggs), recruits age 0, and ratio of SSB over MSST for the GOM king mackerel Final model.

Year	Spawning Biomass	Recruits age 0	SSB/MSST
1981	2123	4487847	0.8117043
1982	2036	4004816	0.7784409
1983	1555	1962239	0.5945361
1984	1590	6391395	0.607918
1985	1502	4472095	0.5742722
1986	1532	3719424	0.5857423
1987	1590	5267802	0.607918
1988	1731	7694286	0.6618277
1989	1748	8987466	0.6683274
1990	1885	8467824	0.7207078
1991	2040	6431419	0.7799702
1992	2215	5865852	0.8468794
1993	2245	9795834	0.8583496
1994	2265	10506494	0.8659964
1995	2210	9132397	0.8449677
1996	2340	6115982	0.8946717
1997	2443	7689198	0.9340526
1998	2509	6440792	0.9592869
1999	2658	5795505	1.0162553
2000	2788	5632798	1.0659593
2001	2876	5702963	1.0996051
2002	2873	6593401	1.0984581
2003	2872	10790938	1.0980757
2004	2955	20369976	1.1298098
2005	3285	16600606	1.2559815
2006	3921	13425502	1.4991487

Table 11. Estimates of fishing mortality at age (FAA) for GOM Final VPA model.

	Age 0	Age 1	Age 2	Age 3	Age 4	Age 5	Age 6	Age 7	Age 8	Age 9	Age 10	Age 11+
1981	0.195	0.014	0.043	0.271	0.34	0.33	0.285	0.266	0.143	0.168	0.033	0.033
1982	0.09	0.037	0.228	0.305	0.46	0.483	1.008	0.3	0.347	0.52	0.448	0.448
1983	0.413	0.063	0.185	0.208	0.079	0.167	0.166	0.233	0.239	0.143	0.061	0.061
1984	0.4	0.04	0.055	0.354	0.427	0.149	0.278	0.203	0.263	0.033	0.075	0.075
1985	0.262	0.014	0.154	0.123	0.19	0.558	0.185	0.107	0.219	0.466	0.086	0.086
1986	0.366	0.027	0.171	0.357	0.062	0.215	0.556	0.102	0.032	0.113	0.086	0.086
1987	0.493	0.099	0.076	0.037	0.186	0.07	0.094	0.201	0.049	0.046	0.047	0.047
1988	0.368	0.036	0.142	0.121	0.097	0.365	0.225	0.235	0.225	0.192	0.239	0.239
1989	0.548	0.058	0.182	0.176	0.137	0.108	0.233	0.107	0.123	0.25	0.123	0.123
1990	0.422	0.051	0.109	0.177	0.24	0.094	0.105	0.212	0.118	0.13	0.132	0.132
1991	0.568	0.084	0.168	0.121	0.176	0.199	0.097	0.047	0.188	0.167	0.105	0.105
1992	0.428	0.045	0.133	0.192	0.137	0.201	0.378	0.099	0.163	0.713	0.206	0.206
1993	0.507	0.039	0.143	0.146	0.216	0.115	0.198	0.357	0.156	0.084	0.25	0.25
1994	0.533	0.054	0.144	0.181	0.233	0.298	0.179	0.356	0.681	0.178	0.38	0.38
1995	0.537	0.019	0.104	0.229	0.227	0.138	0.274	0.113	0.247	0.464	0.133	0.133
1996	0.377	0.041	0.136	0.133	0.187	0.175	0.105	0.221	0.136	0.279	0.288	0.288
1997	0.283	0.032	0.1	0.168	0.124	0.23	0.22	0.186	0.284	0.144	0.294	0.294
1998	0.301	0.025	0.097	0.142	0.208	0.118	0.194	0.175	0.098	0.313	0.081	0.081
1999	0.346	0.024	0.075	0.108	0.155	0.161	0.064	0.194	0.201	0.171	0.07	0.07
2000	0.313	0.039	0.096	0.144	0.159	0.12	0.071	0.096	0.086	0.211	0.111	0.111
2001	0.212	0.029	0.125	0.15	0.138	0.161	0.122	0.142	0.098	0.099	0.15	0.15
2002	0.148	0.038	0.177	0.162	0.166	0.119	0.13	0.105	0.138	0.076	0.126	0.126
2003	0.225	0.012	0.115	0.21	0.177	0.144	0.132	0.113	0.116	0.109	0.1	0.1
2004	0.223	0.01	0.139	0.141	0.214	0.142	0.126	0.114	0.064	0.142	0.054	0.054
2005	0.178	0.004	0.063	0.155	0.195	0.239	0.198	0.171	0.122	0.086	0.089	0.089
2006	0.103	0.004	0.036	0.107	0.208	0.263	0.287	0.243	0.164	0.091	0.087	0.087

Table 12. Estimates of apical F, Fcurrent and ratio of Fcurrent over MFMT for GOM Final VPA model.

Year	Apical F	Fcurr	Fcurr/MFMT
1981	0.340		
1982	1.008		
1983	0.413	0.363	1.443
1984	0.427	0.360	1.431
1985	0.558	0.351	1.397
1986	0.556	0.337	1.342
1987	0.493	0.362	1.439
1988	0.368	0.405	1.611
1989	0.548	0.463	1.844
1990	0.422	0.440	1.750
1991	0.568	0.508	2.023
1992	0.713	0.468	1.863
1993	0.507	0.498	1.980
1994	0.681	0.487	1.939
1995	0.537	0.525	2.091
1996	0.377	0.476	1.895
1997	0.294	0.386	1.534
1998	0.313	0.318	1.265
1999	0.346	0.309	1.229
2000	0.313	0.319	1.271
2001	0.212	0.284	1.131
2002	0.177	0.214	0.852
2003	0.225	0.192	0.763
2004	0.223	0.195	0.776
2005	0.239	0.207	0.826
2006	0.287	0.207	0.825

Table 13. Estimated selectivity by age for fleet-index GOM VPA Final model.

	Age 0	Age 1	Age 2	Age 3	Age 4	Age 5	Age 6	Age 7	Age 8	Age 9	Age 10	Age 11+
Com no Mix	0.000	0.189	0.410	0.573	0.639	0.713	0.681	0.796	1.000	0.633	0.631	0.823
MRFSS	0.000	0.475	0.970	1.000	0.934	0.959	0.931	0.931	0.894	0.982	0.695	0.764
Headboat	0.000	0.280	1.000	0.917	0.564	0.483	0.491	0.378	0.324	0.388	0.187	0.192
SEAMAP Ground	1.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
SEAMAP Plankton	0.000	0.024	0.141	0.278	0.455	0.661	0.801	0.926	1.041	1.145	1.238	1.524

Table 14. Summary of GOM king mackerel stock status in 2006 Fyear.

	N	Deterministic	Avg	Median	low 80% CL	upp 80% CL
SSB2006/MSST		1.498	1.484	1.471	1.237	1.725
Fcurr/MFMT		0.827	0.834	0.828	0.714	0.969
Nboots	1000					
N boots SSB < MSST	3					
N boots Fcurr > MFMT	59					

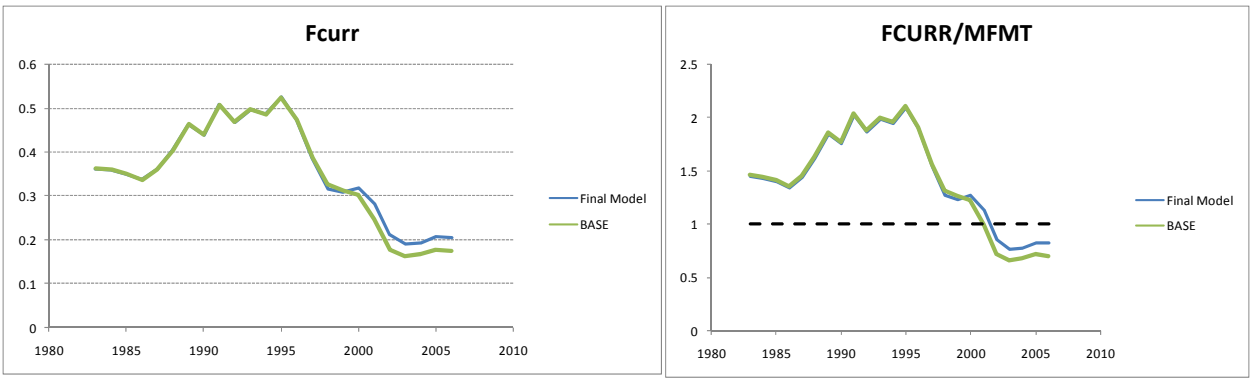


Figure 1. Comparison of fishing mortality trends between the Base GOM VPA model and the Final VPA model GOM as recommended by the review panel SEDAR 16. Fcurr refers to annual fishing mortality rate estimated as maximum F at age of the geometric mean of F at age for the current and two prior years. Maximum fishing mortality threshold (MFMT) is the corresponding fishing at 30% SPR ($F_{30\%SPR}$).

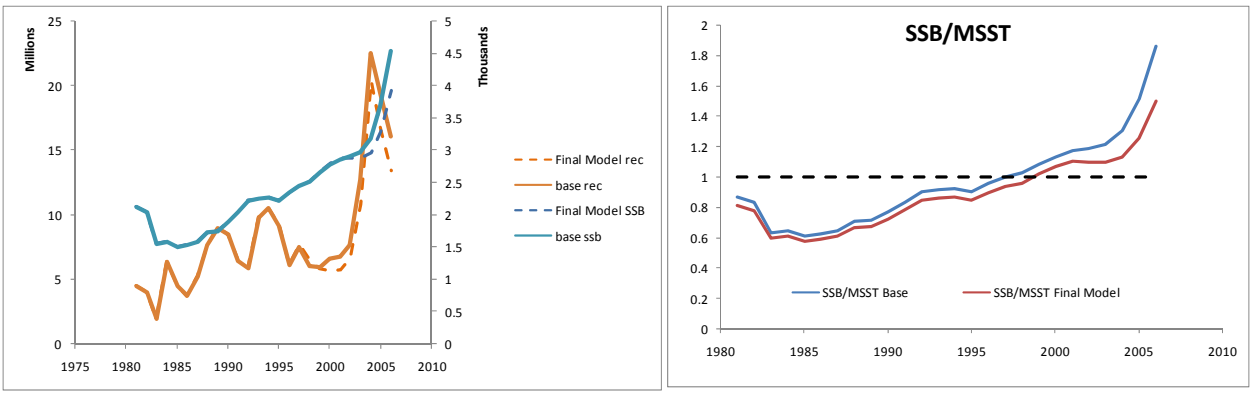


Figure 2. Comparison of recruitment trends (left plot orange lines) in millions of recruits age 0 fish and spawning stock biomass (SSB in million of hydrated eggs) between the base GOM VPA model and the Final VPA model GOM as recommended by the review panel SEDAR 16. Minimum spawning stock threshold is estimated as one minus-natural mortality times the SSB at $F_{30\%SPR}$.

Annex 1

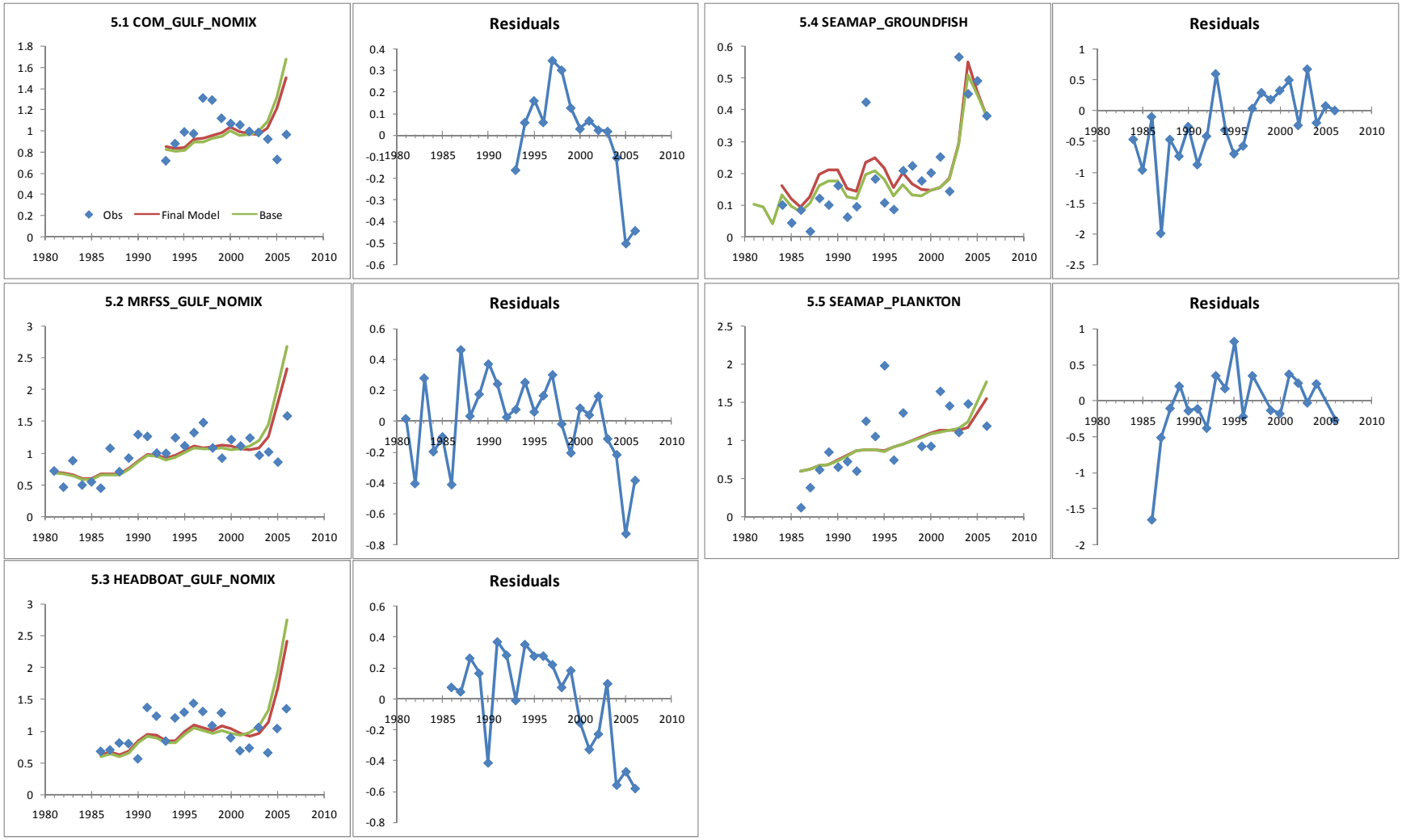
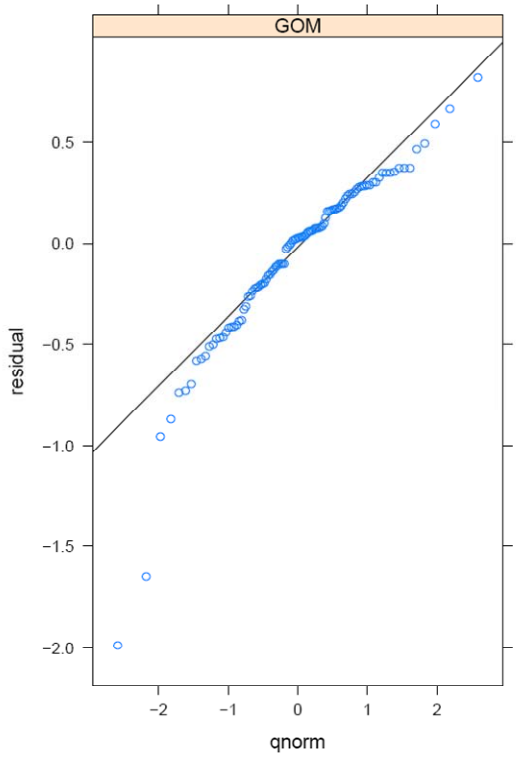


Figure 3. Comparison of fits to relative indices of abundance between the Base GOM VPA model and the Final VPA Model as recommended by the review panel SEDAR 16. Diamond markers are the observed indices, red line represents the final model fit estimation and the green line the Base model fit estimation.



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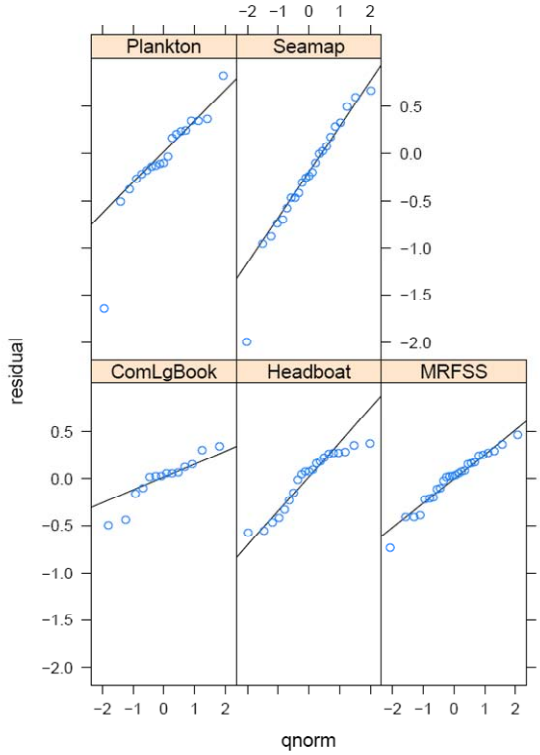

Figure 4. Normalized cumulative residual plots (qq-plots) of the index fits by the VPA GOM Final model. Top plot shows all residuals, bottom plot shows qq-plots by index

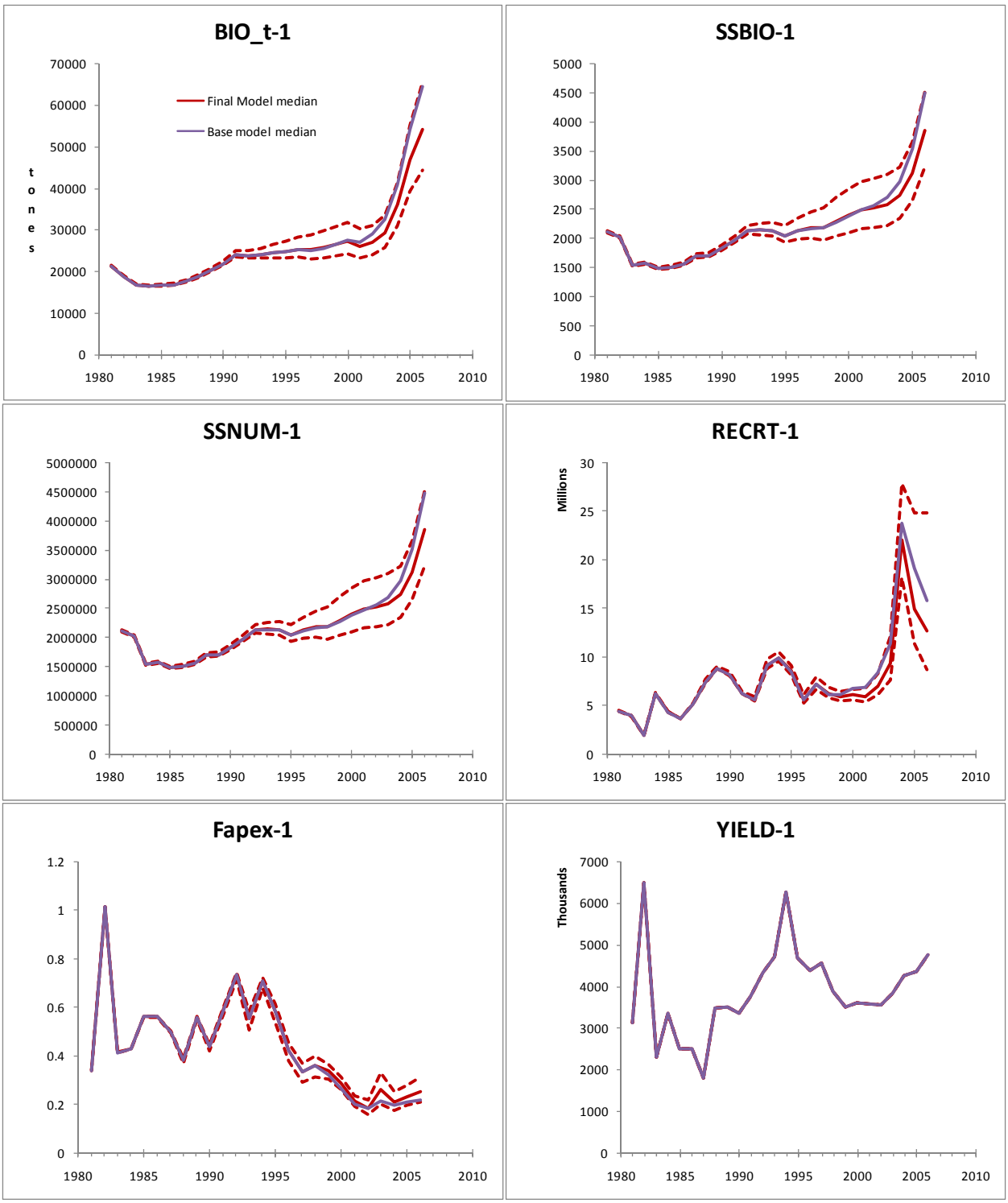

Figure 5. Comparison of total biomass (BIO_t-1), spawning biomass (SSBIO-1), stock size (SSNUM-1), recruits (Recrt-1), apical fishing mortality (Fapex-1), and yield (Yield-1) between the Base VPA model (blue line) and the Final VPA model (red line) for the Gulf of Mexico king mackerel stock unit. Broken lines represent 95% confidence limits estimated from thousand bootstrap runs of the Final VPA model.

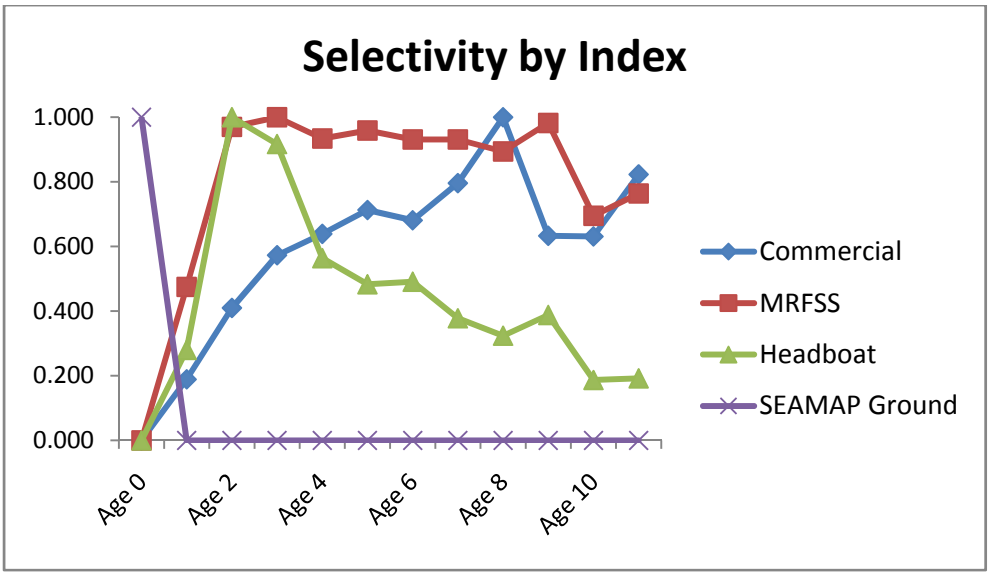

Figure 6. Selectivity by index-fleet estimated for the GOM king mackerel stock unit by the VPA Final model.

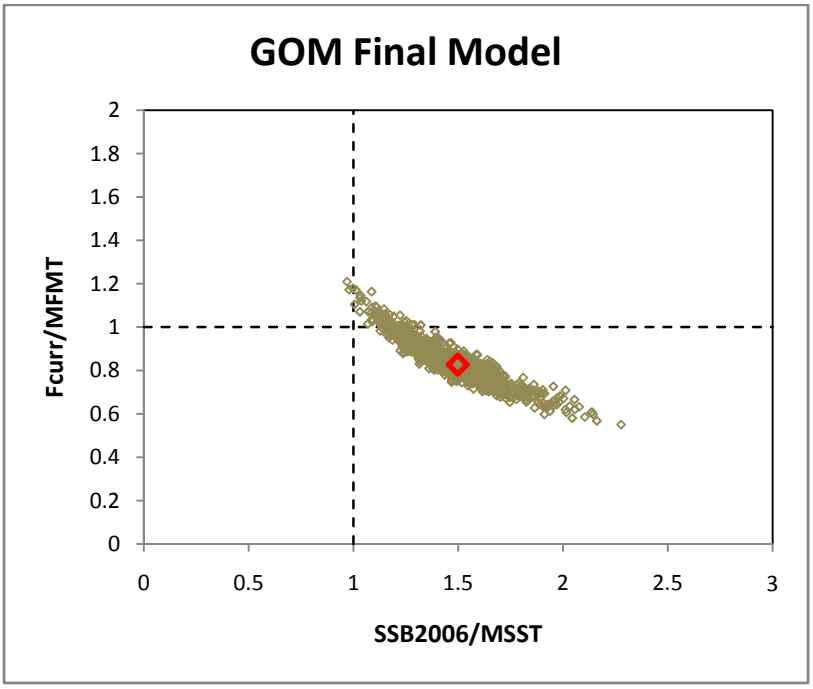

Figure 7. Status or phase plot of the GOM king mackerel stock in 2006 FYear. The red diamond is the deterministic result, other markers are bootstrap results.

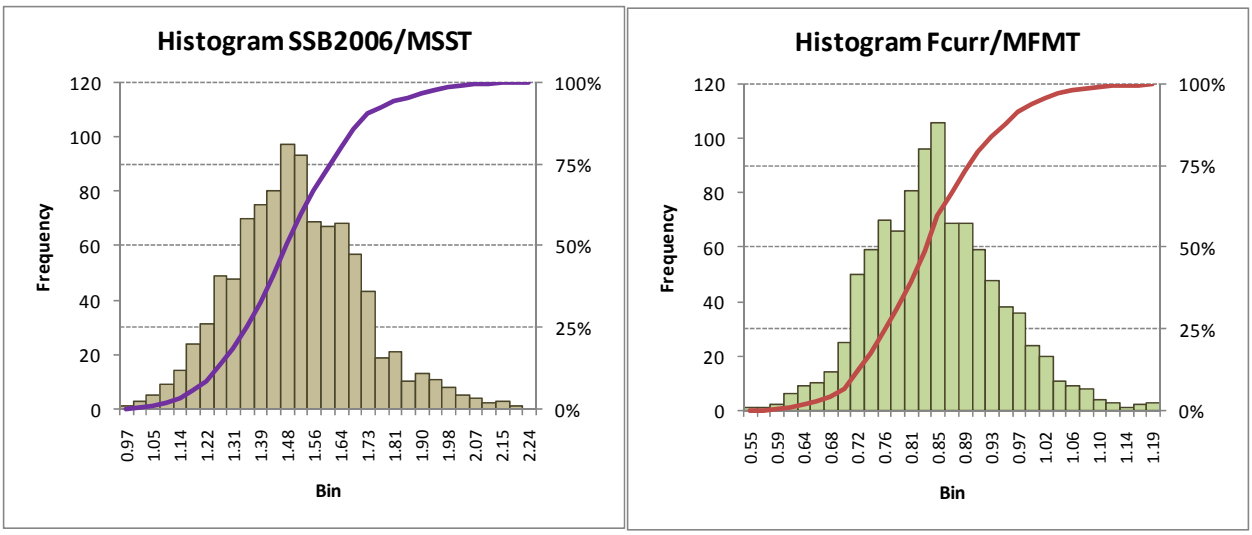

Figure 8. Histogram and cumulative distribution of thousand bootstrap results for the ratios of spawning stock 2006 over MSST (left) and Fcurrent 2006 over MFMT for GOM king mackerel VPA Final model.

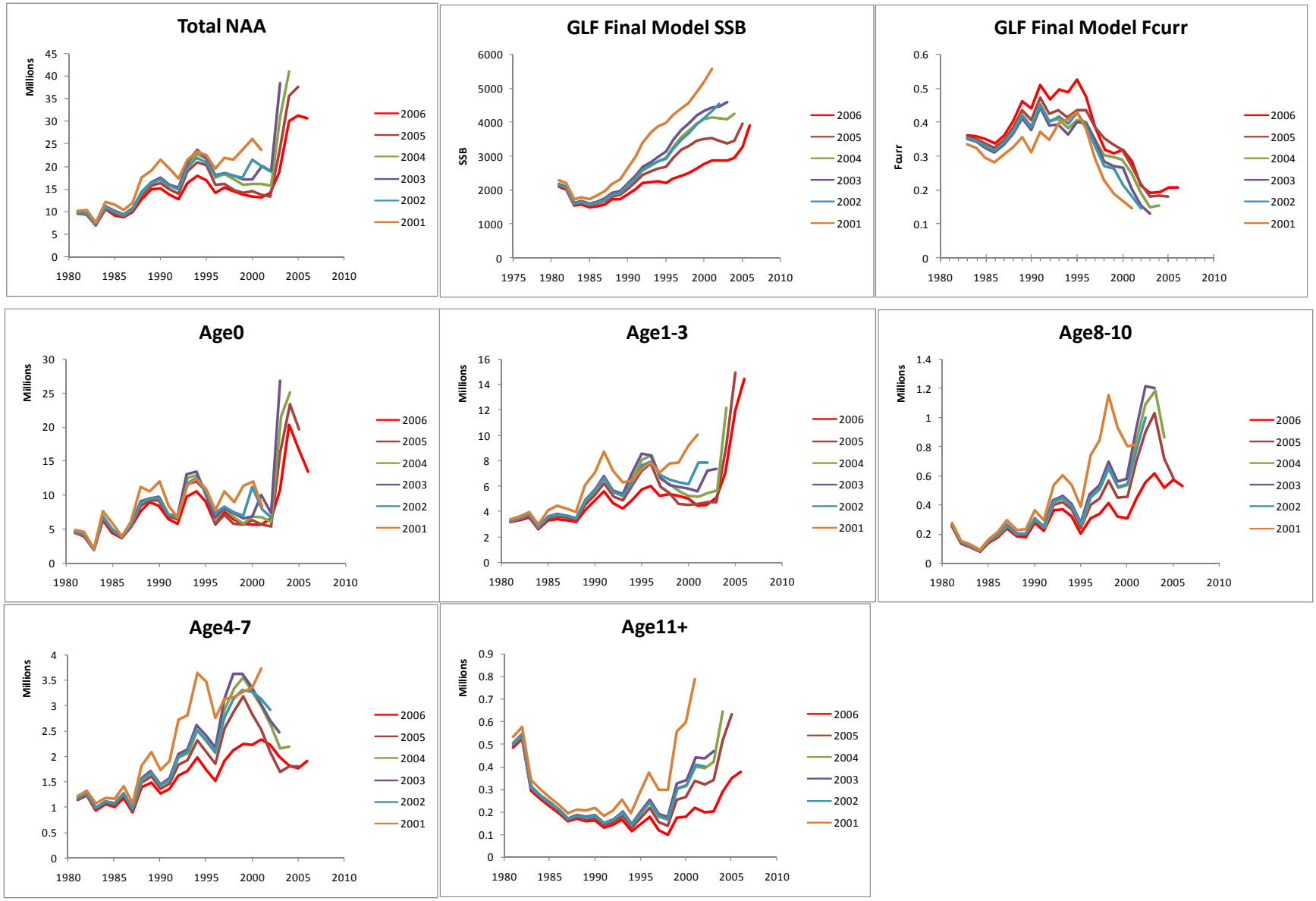

Figure 9. Retrospective patterns GOM king mackerel Final VPA Model.