Modeling Shrimp Fleet Bycatch for the SEDAR9 Assessments

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SUMMARY

Applying the Bayesian bycatch model used for red snapper in SEDAR7 to the SEDAR9 species produced results that were much less satisfying than those for red snapper. The DW recommended scaling back expectations, aiming for a simplified description of bycatch for the SEDAR9 species based on an average of all years, and constructing a variability estimate incorporating both interannual variation and estimation uncertainty. Additional runs after the DW revealed an unexpected sensitivity to the choice of prior for the year effects in the SEDAR9 species, where sensitivity to this prior had been minimal for red snapper. Possible ways to select the priors for SEDAR9 species were examined. All involve preliminary runs on the data, which makes the 'prior' now function more as a constraint than as a pure Bayesian prior. Making new choices did appear to reduce the chance of systematic error, and the anomalously large ranges seen at the DW were also reduced. For gray triggerfish, the new results now make it reasonable to use the individual year values in the assessment models. Vermilion snapper and greater amberjack ranges still seem implausibly large, and it seems unlikely that any reasonable modification of the analysis will change that. The recommendation to use an average value for bycatch across all years is still probably the best choice for these two species.

INTRODUCTION

A new approach for shrimp fleet bycatch estimation was introduced in SEDAR7 (SEDAR7-DW-3 & 54) and adopted as the estimation procedure for red snapper. Applying the same model to the SEDAR9 species produced results that did not seem nearly as satisfactory. The details are in SEDAR9-DW-26, and a summary table of the results appears as Table Cf 2.2.1 and as Table 2.4 in the amberjack and vermilion snapper DW reports, respectively. In brief, individual annual estimates had extremely large uncertainties; variations among years were implausibly large; and there were indications of possible systematic error, based on large differences between model results and approximate calculations based on globally averaged catch rates. The recommendation at the DW was to evaluate ways to extract a single central tendency over years, and to quantify variability in such a way as to incorporate both interannual variation and uncertainty in estimation. Initially, it looked like some very subjective decisions would be necessary to arrive at an appropriate description of bycatch in this format. However, experimenting with the model after the DW revealed that modification of a key prior parameter reduced interannual variability in the results, and brought the central tendencies more in accord with approximate techniques.

I was particularly concerned about the possible systematic error, due to the nature of how the bycatch estimates may have to be used in the more data-poor assessment of SEDAR9 relative to SEDAR7. A full Bayesian assessment technique (recommended for future work by the SEDAR7 RW, but currently still out of reach computationally) could carry the entire uncertainty in the bycatch estimates forward through the assessment. An assessment model like CATCHEM (the choice for red snapper) simply takes note of the large variances for the annual estimates, and then, taking all other information available to it, essentially re-estimates bycatch internally. Neither of these two assessment approaches need be seriously misled if a central tendency statistic for bycatch had some systematic error. However, the SEDAR9 species are relatively data-poor, and simpler assessment models may be needed. These simpler models could be misled by a central tendency statistic with systematic error. Some of the simplest models may be unable to incorporate any information about the uncertainty in the catch estimates. Therefore, I prepared to focus on the central tendency issues.

It was quite by accident, and well after the DW, that I found that changing one prior could reduce the concerns about central tendency. I reran a model run for vermilion snapper to add some additional diagnostic variables, and it produced results dramatically different from those in the summary table in the DW reports. Checking the programs, I found the difference was solely due to a different mean parameter on the priors for the year effects. (I knew I had made the change; I had just expected a minimal effect.) Red snapper had shown nowhere near that sensitivity to the choice in that prior, so I had not up until then investigated it for SEDAR9. I started a more systematic look at the sensitivity to the prior for the SEDAR9 species. I also included red snapper and king mackerel runs for comparison.

METHODS

The core of this analysis consists of varying the mean parameter for the priors for the year effects (labeled 'yx' in what follows) over a range of values for each species, and recording a set of diagnostic statistics for each run (Table 1). I restricted the changes in yx to integer steps (integer powers of e) to keep the number of runs down to a manageable level. (This appears not to have been a serious restriction. The rates of change with the yx mean for many of the statistics considered turned out to be slow, and confidence intervals on adjacent yx runs tended often overlapped broadly.) The ranges chosen were specific to each species, with just enough choices to establish patterns in common and differences in magnitudes among the species. Each run returns a set of posterior distributions (1 for each year) for the yx's. The ranges over the medians of these distributions are recorded in Table 1.

One of the key observations from SEDAR9-DW-26 was the apparent disagreement between the model results and an approximate statistic based on multiplying the global average catch per hour times an arbitrary effort value approximating recent effort levels. I began this round of analysis by making the calculation of approximate statistics a bit more rigorous. Because estimates with BRDs could not be made for triggerfish and amberjack, and came out nonsensical for vermilion snapper, I eliminated all BRD data to compare among species on the same basis. (The DW report tables had included BRD results where possible.) Rather than just assuming a 'recent' value for annual effort, I calculated the median annual effort over the 1972-2004 period, and multiplied it by the median of the mean parameters for nets per vessel for the same period, getting a global average for effort of 11.7 million net-hours per year. I calculated approximate average for CPUE in two ways: the global average of all observations used previously, and a weighted average based on season and spatial stratum averages, ignoring year. In the weighted approximation, the global average CPUE was calculated by multiplying each stratum CPUE by the fraction of annual shrimping effort in each stratum, again averaged over 1972-2004. The point of deriving two approximate statistics was to get a flavor for differences among different analytical choices. The biggest objection to relying on an approximate statistic as an indicator of possible bias is that the observer data are so unbalanced. The whole point of the original GLM structure used in the past, and the similar main effects structure used in the Bayesian model, was to correct for the unbalanced distribution of the data. The second, weighted average provides some partial correction to the unbalanced situation, while retaining some of the 'back of the envelope' lack of complexity of the unweighted global average. The two approximate statistics for each species are shown at the top of each species section in Table 1, labeled Approx 1 (the unweighted case) and Approx 2 (weighted). The units are millions of fish. The CPUEs producing these approximations are shown to the right of the lead line for each species (units are fish per hour), with the natural log of the CPUE printed just below each entry.

For an additional comparison, I ran the old GLM procedure on the current data sets, and added the median of the annual values to Table 1. The figures given are from the ALL version of the analysis, which is the run with all representative non-BRD observer data from all time periods. With evidence of improvement in performance of the original Bayesian approach via change in one parameter, I decided to discontinue work with the delta and 'model 3' approaches that I included at the DW. Neither showed much promise of matching the approximate statistics or reducing the extreme ranges. I did transfer the median of the annual medians from the delta results to Table 1, just as a reminder of the scale of the differences.

I added some statistics to be calculated within the BUGS program. Rather than take the median of the final annual medians as the central tendency, I had the program calculate the median of the annual medians with each iteration, and collect the MCMC-generated frequency distribution for that statistic. This statistic is labeled 'Mofam' (for Median of Annual Medians), and is shown in Table 1 along with its 95% confidence interval. I also added statistics that recorded the maximum annual total and the range (as the ratio of the maximum to the minimum annual value) with every iteration. These two statistics proved less useful. With skew even on the log scale, statistics to track extremes of a distribution come out, well, rather extreme. Although not wrong, they operate on a scale that is not very intuitive. I kept the range statistic (its median) in Table 1 because of its tendency to pass through a minimum as I changed the sensitive prior, but dropped the max annual statistic in favor of tabling the highest value of the medians of the annual totals, and also added a more intuitive indicator of range by taking the ratio of this 'high median' to the median of the mofam statistic. The downside of this intuitive approach is that one gets no direct uncertainty information on these statistics out of the BUGS program.

The statistic tau from the BUGS run was also recorded. Tau is the precision (i.e. 1/variance) of the quasi-random 'Local' effect in the model (extended discussion in SEDAR7-DW-3). The median of its posterior distribution for each run is recorded in Table 1.

Vermilion snapper has an addition statistic recorded: 'Fract E, ' which is the fractional of the annual total bycatch estimated to have been taken east of the Mississippi river. The median value from each run is recorded in Table 1.

Because a large number of runs were required, each run was kept to a minimum number of iterations required to extract reasonably accurate central tendencies for the statistics wanted. I chose 6000 iterations with two chains for this. In this BUGS model, 4000 iterations are required for an 'adapting' phase, during which results are not accumulated as part of the posterior distributions. That left 4000 points to determine each posterior distribution. Even these minimal runs required 6-8 hours each.

RESULTS

Table 1 has the results of all of the runs. I did not try to fill the entire table. A general pattern emerged fairly quickly, so I ran only enough choices to see differences among the species within the general pattern.

The pattern common to all species includes an increasing median (Mofam) statistic with increasing mean of the yx prior. The rate of increase accelerates toward higher values of the prior parameter. The rate of change near the original values used in SEDAR9-DW-26 is explosive for the SEDAR9 species, but minimal for red snapper. Examining individual years (not shown), changes with the yx prior for all species tended to be minimal for data rich years, and much larger for data poor years. The most extreme years in any analysis also tended to be most sensitive.

Several of the diagnostics collected in Table 1 tended to pass through an extreme over the range of yx values considered, and I considered whether any of these would be good candidates for picking a yx value to use in final runs. The two statistics related to range often showed a minimum at intermediate values for the yx prior within the ranges considered. (Triggerfish and red snapper showed a minimum in the 'Range' statistic, but not in the 'High as ratio' statistic; king mackerel did not show a minimum in either). The tau statistic always showed a maximum, although the rates of change were often rather flat.

I elected to use the maximum of the tau statistic to chose the mean of the yx prior for a final run for each species. The runs with maximal tau statistics often brought the two Approx statistics into or at least near the 95% confidence interval for Mofam. (Amberjack was the exception.) The tau maximum was usually near the minima of the range statistics, if those minima existed. The choices based on tau appeared to be good compromises when multiple criteria disagreed.

Taking the yx priors indicated by the tau statistics, I ran much longer production runs (12k runs, yielding 16k points) for to get more accurate statistics for the posterior distributions. BUGS quantiles for annual totals from the runs for the SEDAR9 species are shown in Tables 2-4. Parameters for lognormal approximations to these distributions are collected in Table 5, and parameters for lognormal approximations to the mofam statistics (an 'average' value over all years) are collected in Table 6, along with the fraction of vermilion snapper estimated to have been taken east of the Mississippi river.

DISCUSSION:

The revised priors brought the medians over all years into closer agreement with the 'back of the envelope' approximations, and also brought the ranges over years down to lower levels. The ranges for vermilion snapper and greater amberjack are still implausibly high, enough so that using the annual results may not be a good idea in some assessment models. Annual values for gray triggerfish probably are reliable enough to use in most assessment approaches – even for the highest annual estimate, the 95% confidence band still includes the approximate statistics.

Making a decision about what range is plausible and what is not is necessarily subjective, and I decided I could not make a decision based on the 'Range' statistics of Table 1. My comments in the preceding paragraph are based on the 'High as ratio' statistic. I believe most would accept 5x as a plausible value, and reject 10x as implausible, at least in the absence of other evidence for a change of that magnitude. Where to draw a line between is more problematic, but in this case, we don't have to, as the selected yx's didn't really put the statistics in between.

Using tau to choose the yx prior does not have any special theoretical basis. Tau is maximized when the main effects are contributing their (collective) maximum to the fit over the yx choice range, which is what you would want if the Local effects were mostly noise. However, there is no strong reason to assume the Local effects are not describing some real variation. Another problem with tau was the slow rate of change with yx – slow enough that I suspected the accuracy of tau might be an issue with the short runs used to explore the yx priors. This was confirmed with both red snapper and king mackerel -- in the longer production runs (not presented here), the resulting median of tau dropped below that of one of its neighboring yx choices collected in the short runs. However, this did not occur for the SEDAR9 species.

Ultimately, the causes of the problems encountered with the SEDAR9 analyses remain the underlying data – the non-random, unbalanced sets of observer data that are so far from ideal, but still remain today the best information available. The question for SEDAR9 is why these data interact so poorly with the model structure; whereas for red snapper, the results were much more in line with expectations. I believe there are several reasons, some specific to each species. The species-specific issues were covered in SEDAR9-DW-26. What's going on in general here seems to have little to do with the prior being too restrictive (all versions used very vague priors, and the posterior distributions were often well removed from the center of the prior distribution, and much narrowed.) Changing the priors did move the posteriors more than I expected based on the red snapper results, but that was not the whole story. With the yx prior changed, the model simply adjusted all the other effects to come out with approximately the same estimates for data rich years. However, to get estimates in data poor years, the main effects must be used like partial derivatives. The changes in the fitted parameters that accommodate the changed priors and yet still fit the rich data cells can produce large changes in the estimates in data poor cells. This is always the plague for applications with unbalanced data, not restricted to this Bayesian approach. I suspect the lower abundances of the SEDAR9 species (compared to red snapper) left more freedom for different combinations of main effects to fit the existing data, which led to wilder predictions in the data-poor cells.

How to transmit and use these results in the assessment models will depend in part on the specific assessment models chosen. The DW discussed constructing uncertainty parameters in such a way as to cover both interannual and estimation variation. That won't be necessary for triggerfish if the annual estimates are used, and upon reflection, doesn't seem to be the best choice if an overall central tendency is used. For using an overall average in assessment models with an objective function structure, it would seem better to calculate the a predicted value for the overall 'average bycatch' within the model, and include a single term to minimize distance from the (log) parameters for central tendency in Table 6, perhaps weighted by the Table 6 standard errors.

LITERATURE CITED

All references are to SEDAR7 or SEDAR9 documents.

Table 1. Results of varying the year effects prior. Descriptions of the entries is extensive. See main text.

Vermilion Snapper		**Approx 1:**	7.5	**Approx 2:**	5.9	**GLM:**	1.3	**Delta:**	1.6	**Avg CPUE 1:**	0.64	**Avg CPUE 2:**	0.51
											-0.4		-0.7
Center of yx prior	**3**	**2**	**1**	**0**	**-1**	**-2**	**-3**	**-4**	**-5**	**-6**	**-7**	**-8**	**Comments**
Range of yx medians		-3.5 to 0.8		-4.7 to -0.3	-4.8 to -1.8	-5.3 to -1.6			-6.5 to -4.1				prior increasingly into posterior's range as prior decreases
Mofam		102.3		14.9	9.521	6.024			2.947				-1,-2 both close
CI of mofam		32 to 405		6.4 to 35	4.7 to 21	2.8 to 14			1.4 to 7.0				-1,-2 puts approxes in ci's
High median		1141		136.7	89.46	71.73			50.59				year of max changes over yx range
High as ratio		11.2		9.2	9.4	11.9			17.2				ranges implausibly large; has a minimum
Range		11610		1068	728	717			1404				minimum at -2 or below
Tau		0.136		0.195	0.2016	0.198			0.1317				max at -1
Fract E		0.88		0.77	0.7	0.65			0.53				monotonic

Gray Triggerfish		**Approx 1:**	3.7	**Approx 2:**	4.3	**GLM:**	3.3	**Delta:**	2.2	**Avg CPUE 1:**	0.32	**Avg CPUE 2:**	0.37
											-1.1		-1.0
Center of yx prior	**3**	**2**	**1**	**0**	**-1**	**-2**	**-3**	**-4**	**-5**	**-6**	**-7**	**-8**	**Comments**
Range of yx medians				-4.6 to 0.2	-5.1 to -0.3	-5.9 to -0.7							prior increasingly into posterior's range as prior decreases
Mofam				5.243	3.486	2.533							close to approxes at -1
CI of mofam				3.1 to 9.0	2.2 to 5.6	1.4 to 4.4							approxes are well inside ci's for -1
High median				35.19	17.54	11.88							
High as ratio				6.7	5.0	4.7							5x plausible (others reasonable, too)
Range				317	297	502							min at -1
Tau				0.3616	0.3791	0.3596							max at -1

Greater Amberjack		**Approx 1:**	0.0018	**Approx 2:**	0.0021	**GLM:**	0.51	**Delta:**	0.024	**Avg CPUE 1:**	0.00016	**Avg CPUE 2:**	0.00018
											-8.7		-8.6
Center of yx prior	**3**	**2**	**1**	**0**	**-1**	**-2**	**-3**	**-4**	**-5**	**-6**	**-7**	**-8**	**Comments**
Range of yx medians				-5.2 to -0.4			-6.3 to -2.4	-6.7 to -3.0	-7.2 to -3.3	-7.5 to -5.2		-9.2 to -5.8	gets centered near -5
Mofam				16.2			0.1655	0.06949	0.02933	0.01484		0.005033	poor convergence at -8
CI of mofam				4.3 to 149			0.07 to 0.36	0.03 to 0.16	0.01 to 0.06	0.006 to 0.04		0.0018 to 0.016	-8 barely includes approxes
High median				267.4			2.58	1.046	0.2912	0.1288		0.06955	
High as ratio				16.5			15.6	15.1	9.9	8.7		13.8	implausibly large ranges
Range				7573			490	415	374	532		792	min at -5
Tau				0.2147			0.4361	0.4441	0.4534	0.4177		0.2694	max at -5

Red Snapper		**Approx 1:**	27	**Approx 2:**	30	**GLM:**	26	**Delta:**	13	**Avg CPUE 1:**	2.3	**Avg CPUE 2:**	2.6
											0.8		1.0
Center of yx prior	**3**	**2**	**1**	**0**	**-1**	**-2**	**-3**	**-4**	**-5**	**-6**	**-7**	**-8**	**Comments**
Range of yx medians	-0.9 to 2.3	-1.8 to 1.9	-1.8 to 1.6	-2.0 to 0.8	-2.2 to 0.6	-2.1 to 0.4	-2.9 to -0.06						most centered at -1
Mofam	41.46	38.73	35.84	34.91	32.88	31.94	31						slow change compared to other spp.
CI of mofam	31.5 to 57.4	30.2 to 51.3	27.8 to 52.1	26.9 to 45.5	25.6 to 42.9	24.1 to 42.9	23.6 to 40.6						includes both approxes starting at 0
High median	341.7	269	227.1	140	108.4	99.41	87.69						
High as ratio	8.2	6.9	6.3	4.0	3.3	3.1	2.8						very plausible range for 1 and below
Range	90	74	73	59	63	70	86						min at 0
Tau	0.3951	0.4058	0.4057	0.4083	0.3853	0.3743	0.3389						max at 0

King Mackerel		**Approx 1:**	1.3	**Approx 2:**	1.8	**GLM:**	0.61	**Delta:**	n/a	**Avg CPUE 1:**	0.11	**Avg CPUE 2:**	0.15
											-2.2		-1.9
Center of yx prior	**3**	**2**	**1**	**0**	**-1**	**-2**	**-3**	**-4**	**-5**	**-6**	**-7**	**-8**	**Comments**
Range of yx medians				-4.6 to -0.4	-5 to -1.2	-5.4 to -1.5	-5.7 to -2.2						prior increasingly into posterior's range as prior decreases
Mofam				4.597	2.851	2.269	1.573						consistently above approxes
CI of mofam				2.3 to 10	1.4 to 5.6	1.2 to 4.4	0.8 to 3.1						includes approx 2 starting -1
High median				36.44	15.43	11.79	7.589						
High as ratio				7.9	5.4	5.2	4.8						-1 down certainly plausible
Range				917	686	665	659						no min in this range
Tau				0.2262	0.2514	0.2499	0.2433						max at -1, rate of change slow - beyond accuracy?

Table 2. BUGS quantiles from production run for vermilion snapper. Annual bycatch totals in millions of fish, 1972-2004.

node	2.50%	25.00%	median	75.00%	97.50%
annual[1]	3.277	15.55	38.09	102.5	1042
annual[2]	1.427	6.554	15.65	41.4	421.2
annual[3]	0.5469	2.263	5.308	13.58	118.8
annual[4]	0.3046	1.241	2.935	8.075	74.97
annual[5]	0.1597	0.6896	1.704	4.75	53.9
annual[6]	0.2154	0.8126	1.934	5.124	54.27
annual[7]	2.437	5.746	10.16	19.5	95.59
annual[8]	0.547	3.232	9.038	26.93	271.2
annual[9]	0.3266	0.8784	1.656	3.412	19.85
annual[10]	1.403	4.034	8.122	19.65	177.8
annual[11]	0.3011	1.412	3.414	9.112	80.6
annual[12]	0.2672	1.253	3.132	8.825	83.28
annual[13]	0.8131	3.809	9.13	24.37	238.8
annual[14]	0.6912	3.154	7.773	20.73	198.6
annual[15]	1.7	8.554	20.84	54.84	493.1
annual[16]	2.148	10.38	25.38	67.44	608.8
annual[17]	0.6722	3.432	8.323	22.49	214.4
annual[18]	0.9961	5.082	12.63	34.08	315.1
annual[19]	2.2	9.8	24.36	64.99	580.1
annual[20]	4.342	20.16	47.7	123.9	1090
annual[21]	1.128	2.595	4.757	10.64	100.3
annual[22]	0.6302	1.141	1.739	3.053	19.13
annual[23]	0.7014	1.123	1.529	2.253	7.696
annual[24]	5.282	9.698	14.2	22.58	88.8
annual[25]	1.171	3.736	7.445	16.47	115.2
annual[26]	1.693	5.917	12.69	30.95	221.6
annual[27]	23.16	52.93	91.92	185.5	1345
annual[28]	2.088	10.54	26.1	72.09	773.2
annual[29]	1.632	7.425	18.23	47.73	435.3
annual[30]	5.657	15.06	29.8	70.1	558.8
annual[31]	3.049	4.938	7.246	12.34	62.31
annual[32]	8.409	14.24	20.14	30.62	97.46
annual[33]	0.7561	1.184	1.61	2.464	12.21

efrg BUGS quantiles from production run for gray triggerfish. Annual bycatch totals in millions of fish, 1972-2004.

node	2.50%	25.00%	median	75.00%	97.50%
annual[1]	0.6032	1.855	3.479	6.871	28.43
annual[2]	0.3683	0.837	1.321	2.168	6.627
annual[3]	0.382	0.9445	1.576	2.676	8.885
annual[4]	0.2629	0.6036	1.003	1.802	6.898
annual[5]	0.3839	0.6113	0.8085	1.101	2.234
annual[6]	0.8718	1.362	1.795	2.457	5.31
annual[7]	3.168	5.051	6.776	9.497	21.51
annual[8]	0.4611	1.64	3.126	6.113	24.69
annual[9]	3.227	4.608	5.725	7.313	13.29
annual[10]	1.97	3.572	5.19	8.026	26.37
annual[11]	1.781	3.8	6.009	10.09	34.94
annual[12]	0.3918	1.073	1.858	3.292	12.19
annual[13]	0.7213	1.92	3.312	5.834	20.65
annual[14]	0.3268	0.8495	1.46	2.574	9.45
annual[15]	0.834	2.245	3.999	7.348	26.37
annual[16]	1.043	3.062	5.564	10.46	39.17
annual[17]	0.79	2.262	4.029	7.553	27.93
annual[18]	1.151	3	5.208	9.553	36.5
annual[19]	0.5226	1.464	2.576	4.811	18.22
annual[20]	2.389	6.636	11.72	21.94	81.71
annual[21]	1.735	2.505	3.148	4.123	8.998
annual[22]	4.162	5.972	7.429	9.484	17.22
annual[23]	1.502	3.154	4.912	8.372	30.76
annual[24]	1.278	3.458	6.07	10.77	40.72
annual[25]	1.415	4.022	7.223	13.27	50.42
annual[26]	0.9594	2.611	4.586	8.407	31.06
annual[27]	0.2953	0.7889	1.399	2.56	10.05
annual[28]	1.35	3.636	6.24	11.17	42.51
annual[29]	0.5023	1.464	2.64	5.037	20.64
annual[30]	3.53	10.42	19.15	35.98	146.6
annual[31]	1.103	3.149	5.717	10.72	44.91
annual[32]	0.1747	0.5593	1.045	1.996	8.717
annual[33]	0.01672	0.05916	0.1204	0.2551	1.155

Table 4. BUGS quantiles from production run for greater amberjack. Annual bycatch totals in millions of fish, 1972-2004.

node	2.50%	25.00%	median	75.00%	97.50%
annual[1]	0.001722	0.008802	0.01894	0.04156	0.2041
annual[2]	0.001248	0.004512	0.009002	0.0183	0.08542
annual[3]	0.004764	0.01372	0.02475	0.0452	0.1527
annual[4]	0.00321	0.009267	0.01704	0.03169	0.1111
annual[5]	0.001626	0.004385	0.007746	0.0139	0.04524
annual[6]	0.001007	0.003522	0.006651	0.01293	0.04523
annual[7]	0.003288	0.00934	0.01565	0.02675	0.0789
annual[8]	0.003368	0.01505	0.03169	0.06644	0.3001
annual[9]	0.003288	0.009935	0.01755	0.03172	0.1007
annual[10]	0.001345	0.00426	0.007978	0.01595	0.06066
annual[11]	0.001348	0.005365	0.0107	0.02128	0.08184
annual[12]	0.001619	0.006207	0.01223	0.02388	0.09736
annual[13]	0.004508	0.01486	0.02835	0.05463	0.2117
annual[14]	0.007616	0.02601	0.0495	0.09547	0.3894
annual[15]	0.008972	0.03178	0.06274	0.1247	0.5534
annual[16]	0.006819	0.02416	0.04647	0.09209	0.3874
annual[17]	0.003391	0.0134	0.02741	0.05745	0.2437
annual[18]	0.002001	0.007966	0.01742	0.038	0.1741
annual[19]	0.02601	0.08126	0.1529	0.2939	1.136
annual[20]	0.08506	0.263	0.4775	0.8919	3.347
annual[21]	0.004301	0.01154	0.01885	0.03144	0.09162
annual[22]	0.004552	0.01233	0.01999	0.03279	0.09674
annual[23]	0.00928	0.02466	0.04129	0.07139	0.2385
annual[24]	0.02262	0.0684	0.1251	0.2331	0.9799
annual[25]	0.006553	0.0237	0.0475	0.09647	0.4463
annual[26]	0.07349	0.2057	0.3723	0.7112	2.914
annual[27]	0.002413	0.01047	0.02191	0.04598	0.2189
annual[28]	0.07012	0.207	0.3663	0.6753	2.535
annual[29]	0.00196	0.007772	0.01604	0.03414	0.1528
annual[30]	0.03057	0.1019	0.1966	0.3812	1.537
annual[31]	0.0196	0.05425	0.09644	0.1804	0.662
annual[32]	0.003991	0.01468	0.02889	0.05935	0.2376
annual[33]	0.001719	0.006659	0.01374	0.02913	0.1331

Table 5. Parameters for lognormal approximations to the distributions for the annual totals from the BUGS runs. De-transformed, units will be million of fish.

	Vermilion snapper		Gray triggerfish		Greater Amberjack	
Year	**Mean**	**Std Err**	**Mean**	**Std Err**	**Mean**	**Std Err**
1972	3.64	1.398093	1.247	0.970585	-3.967	1.150499
1973	2.75	1.366217	0.2784	0.705496	-4.71	1.037821
1974	1.669	1.327966	0.4548	0.772087	-3.699	0.883631
1975	1.077	1.388456	0.003078	0.810835	-4.072	0.911059
1976	0.5331	1.430488	-0.2126	0.436196	-4.861	0.855461
1977	0.6594	1.365105	0.5851	0.437442	-5.013	0.964432
1978	2.319	0.905128	1.913	0.467761	-4.158	0.779848
1979	2.201	1.571558	1.14	0.974811	-3.452	1.10009
1980	0.5045	1.005723	1.745	0.342481	-4.042	0.86065
1981	2.095	1.173479	1.647	0.600454	-4.831	0.979258
1982	1.228	1.382378	1.793	0.724251	-4.538	1.021513
1983	1.142	1.447242	0.6196	0.830969	-4.404	0.998532
1984	2.212	1.375854	1.198	0.824104	-3.563	0.965174
1985	2.051	1.395128	0.3784	0.821658	-3.006	0.963691
1986	3.037	1.377337	1.386	0.878664	-2.769	1.013358
1987	3.234	1.387715	1.716	0.911059	-3.069	0.991861
1988	2.119	1.393646	1.394	0.893861	-3.597	1.079334
1989	2.536	1.410695	1.65	0.858426	-4.05	1.158653
1990	3.193	1.402541	0.9463	0.881926	-1.878	0.952572
1991	3.865	1.346202	2.461	0.885854	-0.7392	0.905573
1992	1.56	1.046346	1.147	0.369761	-3.971	0.742783
1993	0.5535	0.72944	2.005	0.343222	-3.912	0.724992
1994	0.4245	0.516316	1.592	0.72351	-3.187	0.787261
1995	2.654	0.626399	1.803	0.842118	-2.078	0.908094
1996	2.007	1.099349	1.977	0.884372	-3.047	1.040786
1997	2.541	1.226112	1.523	0.866803	-0.988	0.919361
1998	4.521	0.929591	0.3357	0.872659	-3.821	1.096384
1999	3.262	1.425522	1.831	0.83174	-1.004	0.876514
2000	2.903	1.379561	0.9707	0.916322	-4.132	1.097125
2001	3.395	1.140121	2.952	0.918472	-1.626	0.978146
2002	1.981	0.679032	1.743	0.908094	-2.339	0.891044
2003	3.003	0.567836	0.04383	0.943231	-3.544	1.035597
2004	0.4765	0.54367	-2.117	1.083782	-4.287	1.09416

Table 6. Parameters for lognormal approximations to the Mofam statistics for central tendency over all years. De-transformed, units will be millions of fish per year. Also, BUGS quantiles for the fraction of the vermilion snapper byatch occurring east of the Mississippi river.

Vermilion snapper		Gray triggerfish		Greater Amberjack	
Mean	Std Err	Mean	Std Err	Mean	Std Err
2.219	0.391	1.29	0.262	-3.844	0.445

Fraction

2.50%	25.00%	median	75.00%	97.50%
0.4684	0.6213	0.6979	0.7694	0.8745