Shrimp Fishery Bycatch Estimates for Gulf of Mexico Vermilion Snapper, 1972-2017

Zhang, X. and J. Isely

SEDAR67-WP-15

5 February 2020

Please cite this document as:

Zhang, X. and J. Isely. 2020. Shrimp Fishery Bycatch Estimates for Gulf of Mexico Vermilion Snapper, 1972-2017. SEDAR67-WP-15. SEDAR, North Charleston, SC. 21 pp.

Shrimp Fishery Bycatch Estimates for Gulf of Mexico Vermilion Snapper, 1972-2017

Zhang, X. and J. Isely

NOAA Southeast Fisheries Science Center
Email: Xinsheng.Zhang@noaa.gov

November 26, 2019

Abstract

Shrimp bycatch estimates for Gulf of Mexico vermilion snapper were generated using the same updated WINBUGS Bayesian approach developed by Nichols and used in the SEDAR 7 Gulf of Mexico red snapper assessment with the SEDAR 9 recommended prior choice for year effect for vermilion snapper. Specifically, the updated model incorporates the estimates of uncertainty for shrimping effort, includes variable "nets per vessel" estimates and separates observer data into BRD and non-BRD datasets. Estimates of shrimp fishery discards for years of 1972-2017 range from 0.155-61.300 millions of vermilion snapper.

Methods

Shrimp bycatch estimates for Gulf of Mexico vermilion snapper were generated using the same updated WINBUGS Bayesian approach developed by Nichols and used in the SEDAR 7 Gulf of Mexico red snapper assessment. Specifically, the updated model incorporates the estimates of uncertainty for shrimping effort and "nets per vessel" estimates and separates observer data into BRD and non-BRD datasets (i.e. modification of the recommended model in Nichols 2004a to the updated model in Nichols 2004b). Although this model is robust for data-rich species such as red snapper, this model was unexpectedly sensitive to the priors used for the year effect for data-poor species such as vermilion snapper. The recommended prior choices for vermilion snapper and other data-poor species were documented in SEDAR 9 (Nichols 2006). A brief summary of the data sources and model is provided in this report, while a more detailed description can be found in Nichols (2004a, 2004b, 2006).

Several datasets were used to estimate shrimp bycatch CPUE. The primary dataset was a series of Southeast shrimp observer program data obtained by onboard observers on shrimp boats, which began in 1972 and extends to the current shrimp observer program (Table 1). These data consist of many different datasets from a diversity of experiments and standard fishery observation. There was some overlap in the use/non-use of BRDs (Table 2). The percentage of positive tows was low (Table 2 and Figure 1). The CPUE from commercial vessel with non-BRD was larger than the CPUE from commercial vessel with BRD for the most of overlapped years (Table 2).

The second primary dataset was the Gulf of Mexico SEAMAP trawl survey, a fishery-independent stratified random survey that uses no BRDs (Table 1). Only data from 40 ft trawls by the Oregon II were used in this analysis, because these trawls were identified as being most similar to trawls conducted by the shrimp fishery. The percentage of positive tows was low (Table 2 and Figure 1). The CPUE from research vessel Oregon II of SEAMAP Gulf trawl survey was larger than the CPUE from commercial vessel (Table 2).

Point estimates and associated standard errors of shrimp effort by year/season/area/depth were generated by the NMFS Galveston Lab using their SN-pooled model (Nance 2004). Some year/season/area/depth-specific strata lacked reported effort (Table 3). Empty strata were restricted to depths greater than 30 fathoms (depth zone=3) where shrimp effort tends to be low. Since the point estimates and associated standard errors of shrimp effort were used to specify year/season/area/depth-specific priors on the predicted effort in the WinBUGS shrimp bycatch estimation model, no strata could remain empty. Therefore, empty strata were filled using the procedure developed in SEADAR 31 (i.e. using the average effort and standard error calculated from the year/season/area/depth-specific strata in the two years preceding and following the empty stratum) (Linton 2012) (Table 3). Furthermore, point estimated standard errors of shrimp effort were zero in some year/season/area/depth-specific strata. As WinBUGS uses a precision term (i.e. 1/variance) to parameterize distributions, a zero standard error will result in an infinite precision. Therefore, zero standard error strata were assigned with a very small assumed standard error (i.e. 0.01) (Table 3). Shrimp effort is used as an index of shrimp fishing mortality in the assessment, in addition to its use in the estimation of shrimp bycatch. Shrimp effort declined sharply from 2002 to 2008, and has remained at relatively low levels from 2008 to 2017 (Table 4 and Figure 2). Most shrimp effort takes place at depths less than 30 fathoms.

Most observer program CPUE data were expressed in fish per net-hour, while the shrimp effort data were expressed in vessel-days. Observer effort was converted from net-hours to net-days, then multiplied by the average number of nets per vessel to convert from net-days to vessel-days. The average and variance of number of nets per vessel were estimated from the Vessel Operating Unit File (VOUF) using the same method developed by Nichols and used in the SEDAR 7 (Nichols 2004b). Both the average and associated variance of number of nets per vessel were used in the Bayesian bycatch estimation model. The average number of nets per vessel increased gradually from 1972 to 1996, and remained relatively constant from 1996 to 2017 at approximately three nets per vessel (Table 5).

The following WinBUGS Bayesian shrimp bycatch model is the same form as updated SEDAR 7 (Nichols 2004b) with the SEDAR 9 recommended prior choice for year effect for king mackerel (Nichols 2006). Uncertainty in observed catch, nets per vessel and shrimping effort estimates was taken into account in this WinBUGS Bayesian shrimp bycatch model.

$$ln(CPUE)_{[i,j,k,l,m]} = year_{[i]} + season_{[j]} + area_{[k]} + depth_{[l]} + dataset_{[m]} + local_{[i,j,k,l,m]} \qquad (Eq1)$$

$$catch_{[i,j,k,l]} = CPUE_{[i,j,k,l,m]} * npv_{[i,j,k,l]} * effort_{[i,j,k,l]} \qquad (Eq2)$$

where $\mathrm{CPUE}_{[i,j,k,l,m]}$ is estimated year/season/area/depth/dataset-specific CPUE, $\mathrm{year}_{[i]}$, $\mathrm{season}_{[j]}$, $\mathrm{area}_{[k]}$, $\mathrm{depth}_{[l]}$ and $\mathrm{dataset}_{[m]}$ are the main effects, $\mathrm{local}_{[i,j,k,l,m]}$ is estimated year/season/area/depth/dataset-specific local term, $catch_{[i,j,k,l]}$ is estimated year/season/area/depth-specific catch, $npv_{[i,j,k,l]}$ is estimated year/season/area/depth-specific nets per vessel and $effort_{[i,j,k,l]}$ is estimated year/season/area/depth-specific effort.

The factor levels for the main effects in Eq1are presented in Table 6. Observed catch in number in each stratum was assumed to follow a negative binomial distribution, which was modeled as a conjugate gamma-Poisson distribution due to computational issues. The main effects and local term are expressed on a log scale, where they are assumed to be additive. Season, area, depth, and dataset effects are centered. The year effect is not centered. The local term was used to model perturbations from main predictions. A lognormal hyperprior was assigned to the precision (i.e. 1/variance) parameter of the local term. Therefore, the data determined the distribution of the local term in strata with data, while the distribution of the local term defaulted to the prior with fitted precision for strata without data. In effect, the local term became a fixed effect for strata with data and a random effect for strata without data. Nichols pointed out in SEDAR 7 (2004a) that for data-poor species such as vermilion snapper and king mackerel, the shapes of the posteriors for the r's of the conjugate gamma-Poisson distribution are clearly dominated by the lower bound of the prior (i.e. 0.03) and may cause the numerical crashes. To evaluate this boundary problem, model runs with both a uniform prior on r (i.e. r~dunif(0.03,5)) and a fixed prior on r (i.e. r=0.03) were carried out respectively in this report (see Appendix A for BUGS code). Please see Nichols (2004a, 2004b and 2006) for detailed description of prior choices.

A brief summary of the procedure for BRD effect is provided in this report, while a more detailed description can be found in Estimated CPUEs were based on a model with BRD and non-BRD observer data as separate datasets, and applying CPUEs from each dataset in time and space in accord with the BRD regulations (i.e. prior 1998: no mandatory BRD requirements, 1988: phased in mandatory BRD requirements; post 1988: mandatory BRD requirements). Because mandatory BRD requirements were phased in during 1998, actual bycatch estimates use the BRD predictions in strata requiring BRDs, and the non-BRD predictions in strata not requiring BRDs. That is, each spatial/temporal stratum is either a BRD stratum or a non-BRD stratum with no attempt to subdivide a stratum to allow for different requirements in differ spatial or temporal areas within stratum, and no attempt to incorporate 'degree of compliance' as a factor. Specifically, all strata prior to 1998 were assumed to be non-BRD strata, all strata of 1998 season 1 were assumed to be non-BRD strata, all strata of 1998 season 2 and area 1 were assumed to be non-BRD strata, all strata of 1998 season 2 and areas 2-4 were assumed to be BRD strata, all strata of 1998 season 3 were assumed to be BRD strata, all strata of post 1998 were assumed to be BRD strata.

The shrimp bycatch estimation models were fit using WinBUGS version 1.4.3. Markov Chain Monte Carlo (MCMC) methods were used to estimate the marginal posterior distributions of key parameters and derived quantities. Two parallel chains of 20,000 iterations were run. The first 4,000 iterations of each chain were dropped as a burn-in period, to remove the effects of the initial parameter values. A thinning interval of five iterations (i.e. only every fifth iteration was saved) was applied to each chain, to reduce autocorrelation in parameter estimates and derived quantities. The marginal posterior distributions were calculated from the saved 6,400 (i.e. (20,000-4,000)/5x2) iterations of two parallel chains. Convergence of the chains was determined by visual inspection of trace plots, marginal posterior density plots, and Gelman-Rubin statistic

(Brooks and Gelman 1998) plots. All annual bycatch and effort estimates are reported or estimated in calendar year.

Results and discussion

Estimates of shrimp fishery bycatch for years of 1972-2017 range from 0.155-61.300 millions of vermilion snapper in the Gulf of Mexico (Table 7 and Figure 3). The estimates of shrimp bycatch have very large confidence intervals in most of years (Table 7). The estimates of shrimp bycatch with a uniform prior on r (i.e. r~dunif(0.03,5)) and a fixed prior on r (i.e. r=0.03) were very similar (Table 7 and Figure 3). Estimates of shrimp fishery bycatch by SEDAR 76 were similar to the previous SDDARs for the overlapping years (Figure 4). The statistics of marginal posterior densities of the grand median of annual median estimates (1972-2017) vermilion snapper as bycatch (millions of fish) in the Gulf of Mexico shrimp fishery are reported in Table 8.

A mandatory observer program for the commercial shrimp fishery operating in the U.S. Gulf of Mexico was implemented in 2007. In June 2008, observer coverage expanded to include the South Atlantic *penaeid* and rock shrimp fisheries through Amendment 6 to the Shrimp Fishery Management Plan for the South Atlantic Region. The Gulf of Mexico WINBUGS Bayesian shrimp bycatch approach was developed prior to the mandatory shrimp observer program. Therefore, this approach might be the 'best' practice during that time for the available poor-quality data. As Nichols (2006) pointed out "all the analytical manipulations cannot completely overcome the limitations imposed by the underlying data. The observer data are still sparse, unbalanced, and non-random. Lack of randomness is a within-cell issue. There are no analytical actions that can make the data more representative, or even evaluate how representative the data are." Both the available shrimp fishery bycatch data and commercial fleet representation through stratified selection have substantially improved since mandatory observer coverage of the shrimp fleet began in 2007. In the next benchmark or research track assessment, we might need to re-visit/modify both the Gulf of Mexico WINBUGS Bayesian shrimp bycatch approach and South Atlantic R GLM shrimp bycatch approach by modeling the data from the poor-quality period and good-quality period (since mandatory observer program) separately. Furthermore, given the South Atlantic R GLM shrimp bycatch approach using a combination of observer data and SEAMAP scientific sampling similar to the Gulf of Mexico WINBUGS Bayesian shrimp bycatch approach, it might be worthwhile to compare these two shrimp bycatch approaches.

Acknowledgments

Special thanks to Elizabeth Scott-Denton for providing the Shrimp Trawl Bycatch Observer Program king mackerel bycatch data, Adam Pollack for providing the GOM SEAMAP data, Rick Hart for providing the GOM shrimp effort data and David Gloeckner and Jade Chau for providing the Vessel Operating Unit File (VOUF).

References

Brooks, S. P., and A. Gelman. 1998. Alternative methods for monitoring convergence of iterative simulations. Journal of Computational and Graphical Statistics. 7: 434-455.

Linton, B. 2012. Shrimp fishery batch estimates for Gulf of Mexico red snapper, 1972-2011. NOAA Southeast Fisheries Science Center, Miami, FL. SEDAR 31-DW-30.

Nance, J. 2004. Estimation of effort in the offshore shrimp trawl fishery of the Gulf of Mexico. NOAA Southeast Fisheries Science Center, Galveston, TX. SEDAR7-DW-24.

Nichols, S. 2004a. Some Bayesian approaches to estimation of shrimp fleet bycatch. NOAA Southeast Fisheries Science Center, Pascagoula, MS. SEDAR7-DW-3.

Nichols, S. 2004b. Update for the Bayesian estimation of shrimp fleet bycatch. NOAA Southeast Fisheries Science Center, Pascagoula, MS. SEDAR7-DW-54.

Nichols, S. 2006. Modeling Shrimp Fleet Bycatch for the SEDAR9 Assessments. NOAA Southeast Fisheries Science Center, Pascagoula, MS. SEDAR9-AW-03

Table 1. Datasets used in the estimation of shrimp bycatch CPUES for the Gulf and South Atlantic. Sets 3-12 are historical datasets and do not need to be updated.

Set	BRD	Use	Gulf/SA	DSET	CPUE Name	Description
1	No	Yes	Gulf	R	OREGON1	Research SEAMAP Gulf trawl survey, 1972-
2	No	Yes	SA	SEAMAP	SEAMAP_ATL	Research SEAMAP Atlantic trawl survey, 1989-
3	No	Yes	Gulf	C	COLDOBS1	Old Observer, 1972-1985, assume no BRDs or TEDs
4	No	Yes	Gulf	C	RRPCHAR1	Historical Observer, 1992-1997, characterization
5	No	Yes	Gulf	C	RRPEVAL1	Historical Observer, 1992-1997, paired RRPBRDS1
6	No	Snapper only	Gulf	C	RRPONLY1	Historical Observer, 1992-1997, paired RRPBNLY1
7	Yes	Yes	Gulf	B	RRPBRDS1	Historical Observer, 1992-1997, paired RRPEVAL1
8	Yes	Snapper only	Gulf	B	RRPBNLY1	Historical Observer, 1992-1997, paired RRPONLY1
9	No	Yes	Gulf	C	FDEVAL1	BRD study, 1998, paired FDBRDS1
10	Yes	Yes	Gulf	B	FDBRDS1	BRD study, 1998, paired FDEVAL1
11	Yes	Snapper only	Gulf	B	FDBNLY1	BRD study, 1998, paired FDONLY1
12	No	Snapper only	Gulf	C	FDONLY1	BRD study, 1998, paired FDBNLY1
13	No	Snapper only	Gulf/SA	C	MOACO1	SIXTH SET, Modern Observer, 1997-, paired MOAEO1
14	Yes	Snapper only	Gulf/SA	B	MOAEO1	FIFTH SET, Modern Observer, 1997-, paired MOACO1
15	Yes	Yes	Gulf/SA	B	MOAEB1	THIRD SET, Modern Observer, 1997-, paired MOACN1
16	No	Yes	Gulf/SA	C	MOACN1	FOURTH SET, Modern Observer, 1997-, paired MOAEB1
17	Yes	Snapper only	Gulf	B	MOECB1	SECOND, EFFORT PROJECT, 1999-2010, CTRL
18	Yes	Snapper only	Gulf	B	MOEEB1	FIRST SET, EFFORT PROJECT, 1999-2010, EXPTL

DSET C: Commercial vessel with no-BRD
DSET D: Commercial vessel with BRD
DEST R: Research vessel Oregon II of SEAMAP Gulf trawl survey
DEST SEAMAP: Research vessel SEAMAP Atlantic trawl survey

Table 2. Observed number of tows, percentage of positive tows and catch per unit efforts (CPUEs) from datasets commercial vessel with no-BRD, commercial vessel with BRD, research vessel Oregon II of SEAMAP Gulf trawl survey in the Gulf of Mexico.

Year	Tows			Percentage positive			CPUE (fish/net-hour)		
	BRD	no-BRD	SEAMAP-GOM	BRD	no-BRD	SEAMAP-GOM	BRD	no-BRD	SEAMAP-GOM
1972		10	635		10.00%	2.68%		2.100	0.543
1973		81	1136		0.00%	2.82%		0.000	1.202
1974		80	1933		0.00%	0.88%		0.000	0.307
1975		175	1702		1.14%	0.35%		0.037	0.081
1976		315	1631		0.00%	1.16%		0.000	0.478
1977		263	1298		0.38%	0.77%		0.051	0.475
1978		266	1095		6.02%	4.47%		1.478	2.630
1979		1	745		0.00%	0.00%		0.000	0.000
1980		296	1479		1.35%	0.14%		0.103	0.016
1981		192	1546		1.56%	0.45%		0.239	0.410
1982		56	1497		0.00%	0.80%		0.000	0.155
1983			1180			0.68%			0.074
1984			1455			1.24%			0.213
1985			661			1.21%			0.290
1986			433			4.16%			0.573
1987			395			3.04%			0.393
1988			418			1.20%			0.049
1989			420			2.62%			0.156
1990			491			3.05%			0.338
1991			488			7.38%			1.106
1992		635	476		4.25%	2.31%		0.074	0.172
1993	196	1234	500	4.08%	2.76%	5.40%	0.035	0.072	0.784
1994	153	855	477	1.31%	3.63%	5.24%	0.017	0.164	0.902
1995	139	482	435	6.47%	9.34%	5.52%	0.171	1.412	0.454
1996	7	158	464	0.00%	3.16%	6.47%	0.000	0.168	0.775
1997	6	103	434	16.67%	3.88%	5.07%	0.142	0.040	0.555
1998	63	64	387	4.76%	6.25%	3.10%	4.288	2.424	0.114
1999			509			3.93%			0.488
2000			491			5.09%			0.517
2001	665	481	356	7.67%	5.41%	4.21%	0.442	0.519	0.500
2002	1987	1587	469	4.13%	4.60%	7.25%	0.221	0.243	1.031
2003	793	806	422	4.79%	5.83%	2.84%	0.791	0.929	0.414
2004	1097	1074	413	4.19%	4.19%	6.78%	0.220	0.320	0.675
2005	527	514	233	13.09%	13.81%	3.43%	3.022	3.364	0.477
2006	31		385	12.90%		2.08%	0.726		0.160
2007	1474		422	7.87%		5.21%	0.619		0.379
2008	3411	41	553	6.07%	0.00%	5.06%	0.304	0.000	0.887
2009	3145	55	622	3.56%	0.00%	5.79%	0.237	0.000	0.926
2010	2630	25	410	4.11%	0.00%	7.56%	0.238	0.000	2.234
2011	2935	130	331	2.15%	31.54%	6.65%	0.103	3.788	1.586
2012	3167	53	369	4.99%	3.77%	10.30%	0.123	0.082	2.476
2013	3810	9	222	2.36%	0.00%	9.46%	0.052	0.000	1.369
2014	4446	30	380	1.39%	6.67%	8.68%	0.031	1.485	2.287
2015	3567		382	0.98%		9.42%	0.027		2.137
2016	4687	37	405	1.56%	0.00%	10.37%	0.033	0.000	3.839
2017	5487		385	2.93%		13.77%	0.068		2.387
Totals or Averages	44423	10108	31570	3.37%	4.79%	3.06%	0.191	0.559	0.664

Table 3. Filled Gulf of Mexico shrimp fishery effort (vessel-days) and standard error values for missing effort, missing standard error and zero standard error strata. Empty strata were filled using the average effort and standard error calculated from the year/season/area/depth-specific strata in the two years preceding and following the empty stratum. Zero standard error strata were assigned with a very small assumed standard error (i.e. 0.01).

YEAR	AREA	SEASON	DEPTH ZONE	OBS	EFFORT	Std Error	Filled EFFORT	Filled Std Error
1974	2	3	3	2	9.14	0	9.14	0.01
1977	2	2	3		NA	NA	114.27	2.02
1977	2	3	3		NA	NA	1130.19	13.20
1984	1	3	3		NA	NA	71.07	2.34
1986	2	3	3	0	0.22	0	0.22	0.01
1989	1	2	3		NA	NA	75.40	1.70
1990	1	3	3		NA	NA	64.53	1.46
1996	1	3	3		NA	NA	170.98	7.55
2002	2	2	3		NA	NA	181.69	2.72
2010	2	2	3	1	0	NA	0	0.01
2012	1	1	3	0	0	NA	0	0.01
2012	1	2	3	2	0	NA	0	0.01
2012	1	3	3	2	0	NA	0	0.01
2013	1	2	3	4	0	NA	0	0.01
2013	1	3	3	0	NA	NA	64.03	1.04

Table 4. Gulf of Mexico shrimp fishery effort (vessel-days) and standard error. The reported effort and standard error values included the average values used to fill empty year/season/area/depth-specific strata (calendar year).

Year	Effort	SE
1972	157194	433
1973	146089	494
1974	146415	454
1975	128520	331
1976	154475	521
1977	167552	618
1978	202002	1075
1979	211497	1677
1980	144256	870
1981	176727	391
1982	173894	425
1983	171311	582
1984	191810	572
1985	196628	497
1986	226798	613
1987	241902	792
1988	205812	662
1989	221240	815
1990	211924	790
1991	223388	775
1992	216669	774
1993	204482	784
1994	195742	939
1995	176589	620
1996	189824	671
1997	207912	715
1998	216999	822
1999	200475	745
2000	192073	725
2001	197644	814
2002	206802	992
2003	168135	640
2004	146624	479
2005	102840	368
2006	92372	276
2007	80733	241
2008	62797	615
2009	76508	187
2010	60518	168
2011	66777	166
2012	70505	201
2013	64828	216
2014	73683	282
2015	66849	227
2016	72609	216
2017	72540	211

Table 5. Average number of nets per vessel in the Gulf of Mexico shrimp fishery calculated from Vessel Operating Units File data (calendar year).

YEAR	Nets	StdDev
1972	1.87	0.08
1973	1.88	0.08
1974	1.87	0.08
1975	1.88	0.09
1976	1.95	0.11
1977	2.14	0.13
1978	2.26	0.16
1979	2.37	0.19
1980	2.44	0.21
1981	2.47	0.24
1982	2.49	0.25
1983	2.46	0.25
1984	2.43	0.27
1985	2.42	0.26
1986	2.42	0.26
1987	2.51	0.25
1988	2.52	0.26
1989	2.55	0.23
1990	2.61	0.26
1991	2.77	0.24
1992	2.67	0.22
1993	2.67	0.23
1994	2.67	0.24
1995	2.85	0.24
1996	2.96	0.22
1997	2.95	0.21
1998	2.84	0.12
1999	2.97	0.22
2000	2.99	0.25
2001	2.99	0.22
2002	3.01	0.20
2003	3.02	0.20
2004	2.96	0.08
2005	2.80	0.25
2006	2.96	0.29
2007	2.85	0.32
2008	2.85	0.31
2009	3.17	0.76
2010	2.91	0.40
2011	2.70	0.33
2012	2.73	0.37
2013	2.77	0.37
2014	2.74	0.36
2015	2.76	0.36
2016	2.69	0.33
2017	2.88	0.35

Table 6. List of factor levels for the main effects of the WinBUGS Bayesian shrimp bycatch estimation model.

Main Effect	Levels	Description
Year	46	1972-2017 Note: Prior 1998: no mandatory BRD requirements 1988: phased in mandatory BRD requirements Post 1988: mandatory BRD requirements
Season	3	Season 1 (January-April) Season 2 (May-August) Season 3 (September-December)
Area	4	Area 1 (Statistical grids 1-9) Area 2 (Statistical grids 10-12) Area 3 (Statistical grids 13-17) Area 4 (Statistical grids 18-21)
Depth	3*	Depth 1 (<= 10 fathoms) Depth 2 (>10 fathoms and <=30 fathoms) Depth 3 (>30 fathoms)
Dataset	3	Dataset 1 (Observer no-BRD) Dataset 2 (Research vessel) Dataset 3 (Observer BRD)

*Decision 7 on page 75 of Section II (Data Workshop Report) of SEDAR 31 – Gulf of Mexico Red Snapper Stock Assessment Report (2013).
The three depth zone run was chosen to provide shrimp bycatch estimates for the assessment, because this run incorporates finer spatial resolution in the data. In particular, the three depth zone run includes the 10 fm to 30 fm zone where the majority of red snapper (i.e., approximately 80% according to observer program data) are thought to be caught by the shrimp fishery.

Table 7A. Statistics of marginal posterior densities of annual estimates (median) vermilion snapper as bycatch (millions of fish) in the Gulf of Mexico shrimp fishery for the base run (calendar year).

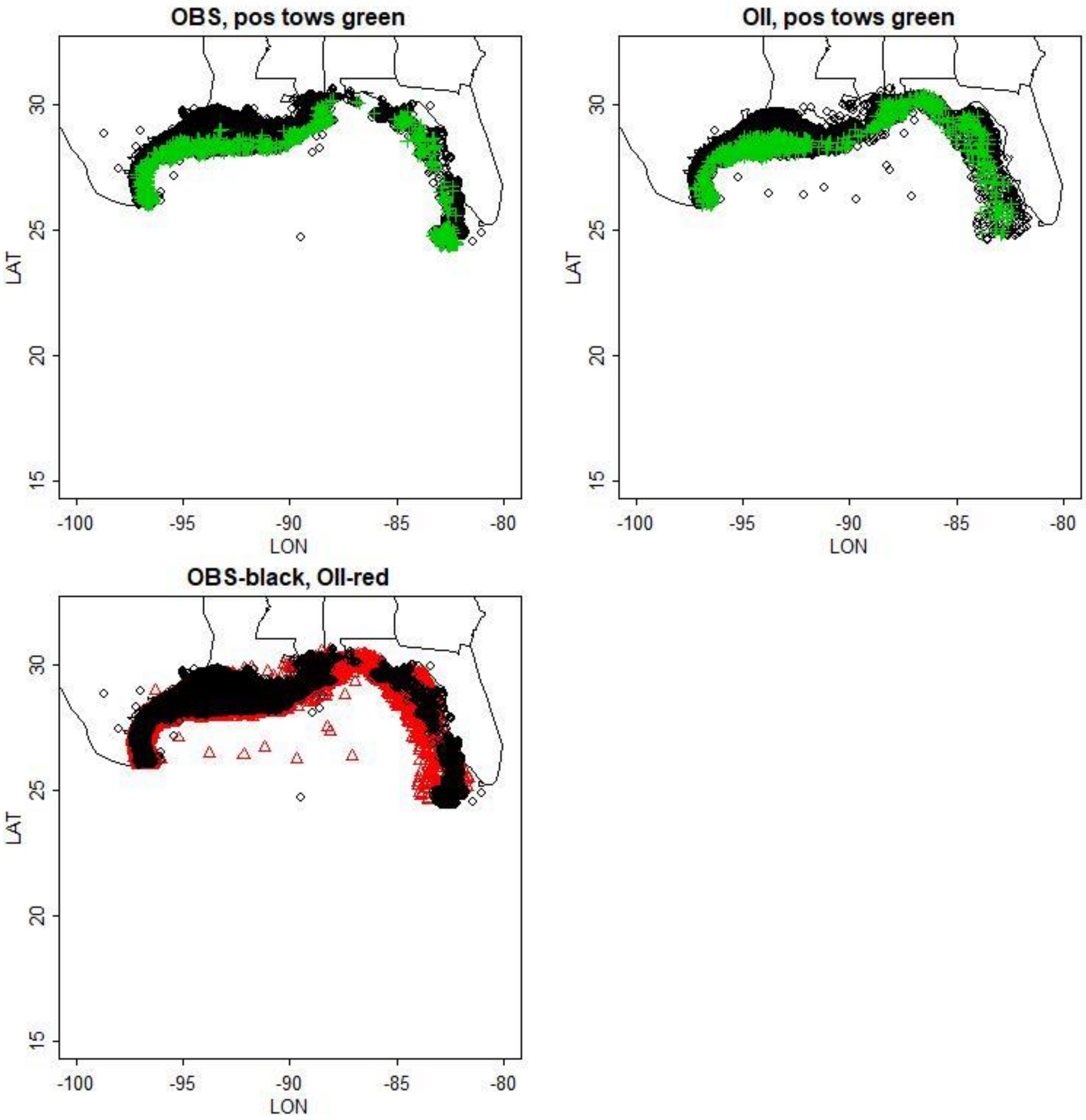
Year	mean	sd	MC error	2.50%	median	97.50%
1972	227.900	1356.000	20.010	3.250	43.450	1286.000
1973	113.900	484.900	6.819	2.850	28.340	684.500
1974	26.860	107.000	1.812	0.690	6.814	174.800
1975	37.660	1532.000	19.300	0.485	4.828	112.400
1976	17.060	124.800	1.579	0.312	3.505	90.140
1977	9.388	88.370	1.140	0.238	2.110	50.730
1978	25.480	191.700	2.460	2.402	10.090	115.100
1979	39.450	205.100	3.265	0.599	9.445	238.400
1980	4.510	19.100	0.287	0.245	1.442	26.510
1981	55.450	633.100	7.782	1.972	12.630	281.900
1982	18.600	97.910	1.501	0.386	4.254	111.100
1983	27.260	181.900	2.637	0.472	5.555	163.900
1984	57.410	609.200	10.480	1.281	12.770	253.200
1985	48.010	281.700	3.856	1.048	11.430	282.000
1986	95.050	499.100	7.009	1.834	21.760	578.200
1987	139.200	1411.000	20.510	1.700	23.390	653.100
1988	49.010	425.800	5.641	0.671	8.487	237.600
1989	59.180	318.000	4.841	1.112	12.920	353.900
1990	76.820	381.700	5.564	1.394	17.150	474.100
1991	251.200	1046.000	17.340	5.434	61.300	1556.000
1992	21.880	373.100	5.334	0.819	4.194	100.900
1993	6.494	48.670	0.627	0.598	2.023	33.250
1994	6.299	32.070	0.487	0.842	2.439	31.560
1995	24.150	97.420	1.355	2.797	9.974	116.900
1996	48.000	206.500	3.328	1.615	11.910	298.200
1997	47.340	278.600	3.780	1.396	11.070	262.200
1998	141.400	657.000	8.370	6.146	36.260	820.900
1999	33.220	169.600	2.335	0.681	7.996	191.300
2000	43.130	651.900	8.150	0.770	8.949	216.200
2001	16.760	154.200	1.987	1.777	5.545	80.920
2002	14.070	69.010	0.917	2.098	5.394	67.070
2003	16.860	33.260	0.475	3.314	9.549	76.350
2004	9.039	62.810	0.727	0.842	2.561	38.720
2005	13.570	62.370	0.769	1.576	4.778	65.360
2006	15.350	85.920	1.162	0.529	4.189	94.530
2007	23.220	168.800	2.349	2.077	6.844	113.700
2008	1.655	3.546	0.053	0.591	1.038	6.340
2009	4.382	60.040	0.744	0.974	2.106	12.700
2010	2.949	40.800	0.508	0.533	1.111	8.718
2011	1.734	11.750	0.150	0.357	0.852	6.508
2012	0.680	2.271	0.029	0.254	0.443	2.088
2013	0.923	3.313	0.043	0.260	0.574	3.372
2014	0.586	4.074	0.054	0.144	0.291	2.183
2015	0.442	2.907	0.037	0.075	0.179	1.932
2016	0.261	1.006	0.014	0.089	0.155	0.876
2017	0.248	0.182	0.003	0.142	0.212	0.560

Table 7B. Statistics of marginal posterior densities of annual estimates (median) vermilion snapper as bycatch (millions of fish) in the Gulf of Mexico shrimp fishery for the fixed r=0.03 run (calendar year).

Year	mean	sd	MC error	2.50%	median	97.50%
1972	205.800	1103.000	17.110	3.239	42.190	1262.000
1973	175.800	2263.000	31.200	2.997	30.170	837.500
1974	31.110	316.600	4.387	0.725	6.847	160.700
1975	20.940	180.200	2.303	0.425	4.596	109.200
1976	14.270	71.670	1.123	0.305	3.303	84.950
1977	9.769	79.290	1.323	0.223	2.079	50.100
1978	23.190	89.020	1.196	2.416	9.960	112.400
1979	43.080	561.400	7.316	0.515	7.283	234.600
1980	5.554	45.480	0.583	0.230	1.458	27.070
1981	44.060	181.200	2.662	1.876	12.360	263.400
1982	24.210	233.900	3.344	0.437	4.650	126.400
1983	22.660	130.200	1.808	0.477	5.194	127.400
1984	53.450	351.800	4.957	1.165	12.120	296.200
1985	46.340	229.500	3.554	0.956	11.730	263.700
1986	93.080	857.900	12.260	1.745	20.160	481.200
1987	85.450	283.100	4.243	1.830	22.500	566.500
1988	35.140	187.900	3.004	0.670	8.363	214.000
1989	61.670	341.300	4.935	1.017	12.410	335.500
1990	86.610	1182.000	15.250	1.362	17.530	507.100
1991	233.100	1120.000	15.430	4.975	58.920	1335.000
1992	18.100	99.700	1.337	0.830	4.325	107.900
1993	6.466	51.170	0.677	0.593	1.966	30.140
1994	6.578	38.090	0.650	0.832	2.451	29.770
1995	24.870	149.400	2.150	2.660	9.582	111.900
1996	47.610	305.800	5.001	1.499	11.380	275.500
1997	42.520	219.500	3.250	1.283	10.870	267.400
1998	153.900	1744.000	23.160	5.954	34.500	826.000
1999	32.710	154.000	2.639	0.704	7.820	191.700
2000	37.030	212.300	3.388	0.852	8.794	217.900
2001	15.170	69.130	0.900	1.745	5.372	85.950
2002	15.680	94.720	1.166	2.111	5.476	66.850
2003	19.240	92.160	1.241	3.415	9.436	72.490
2004	8.316	55.340	0.687	0.875	2.539	44.590
2005	15.260	138.200	1.830	1.609	4.966	67.400
2006	18.150	173.600	2.257	0.528	4.261	87.210
2007	18.070	89.650	1.281	2.026	6.498	92.990
2008	1.722	4.878	0.090	0.585	1.045	6.530
2009	4.226	19.040	0.238	0.992	2.164	14.750
2010	2.352	13.190	0.179	0.540	1.098	8.524
2011	1.812	9.207	0.112	0.357	0.844	7.786
2012	0.669	1.575	0.024	0.254	0.446	2.250
2013	0.851	2.197	0.031	0.268	0.569	2.900
2014	0.539	2.637	0.036	0.145	0.290	2.043
2015	0.370	1.189	0.015	0.073	0.175	1.680
2016	0.241	1.049	0.013	0.087	0.150	0.742
2017	0.254	0.397	0.005	0.143	0.212	0.555

Table 8. Statistics of marginal posterior densities of the grand median of annual median estimates (1972-2017) vermilion snapper as bycatch (millions of fish) in the Gulf of Mexico shrimp fishery for the base and fixed r=0.03 runs.

Model Run	Mean	SD	MC error	2.50%	Median	97.50%
SEDAR 67: base	5.358	1.743	0.072	2.854	5.039	9.562
SEDAR 67: fixed r=0.03	5.279	1.677	0.070	2.891	4.989	9.363


OBS, pos tows green

OII, pos tows green

OBS-black, OII-red

Figure 1. Spatial plots of shrimp observer data and Oregon II of SEAMAP data with positive tows shown in green and overlap of Oregon II of SEAMAP (red) and Observer (black).

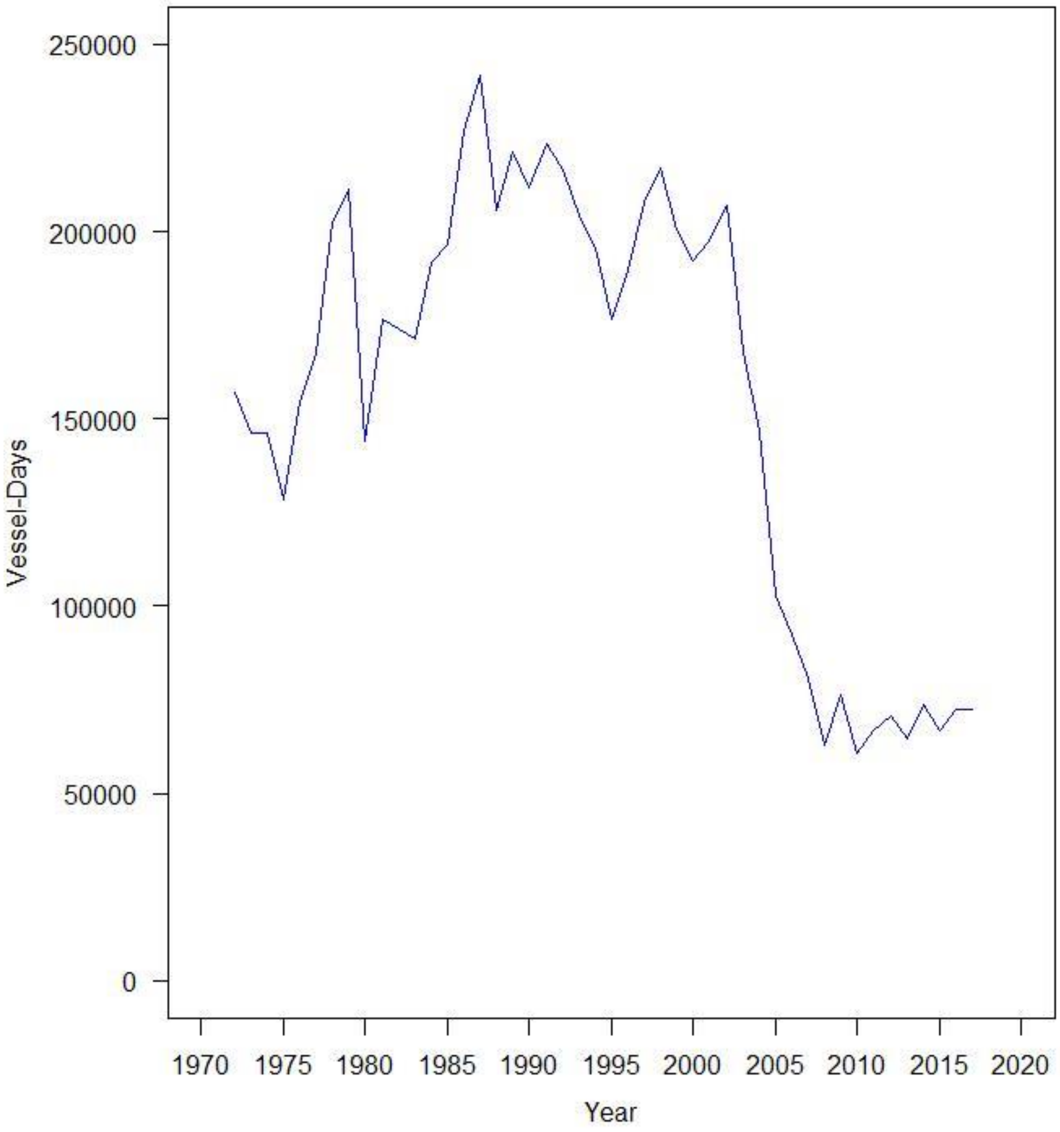


Figure 2. Gulf of Mexico shrimp fishery effort (vessel-days) provided by the NMFS Galveston Lab (calendar year).

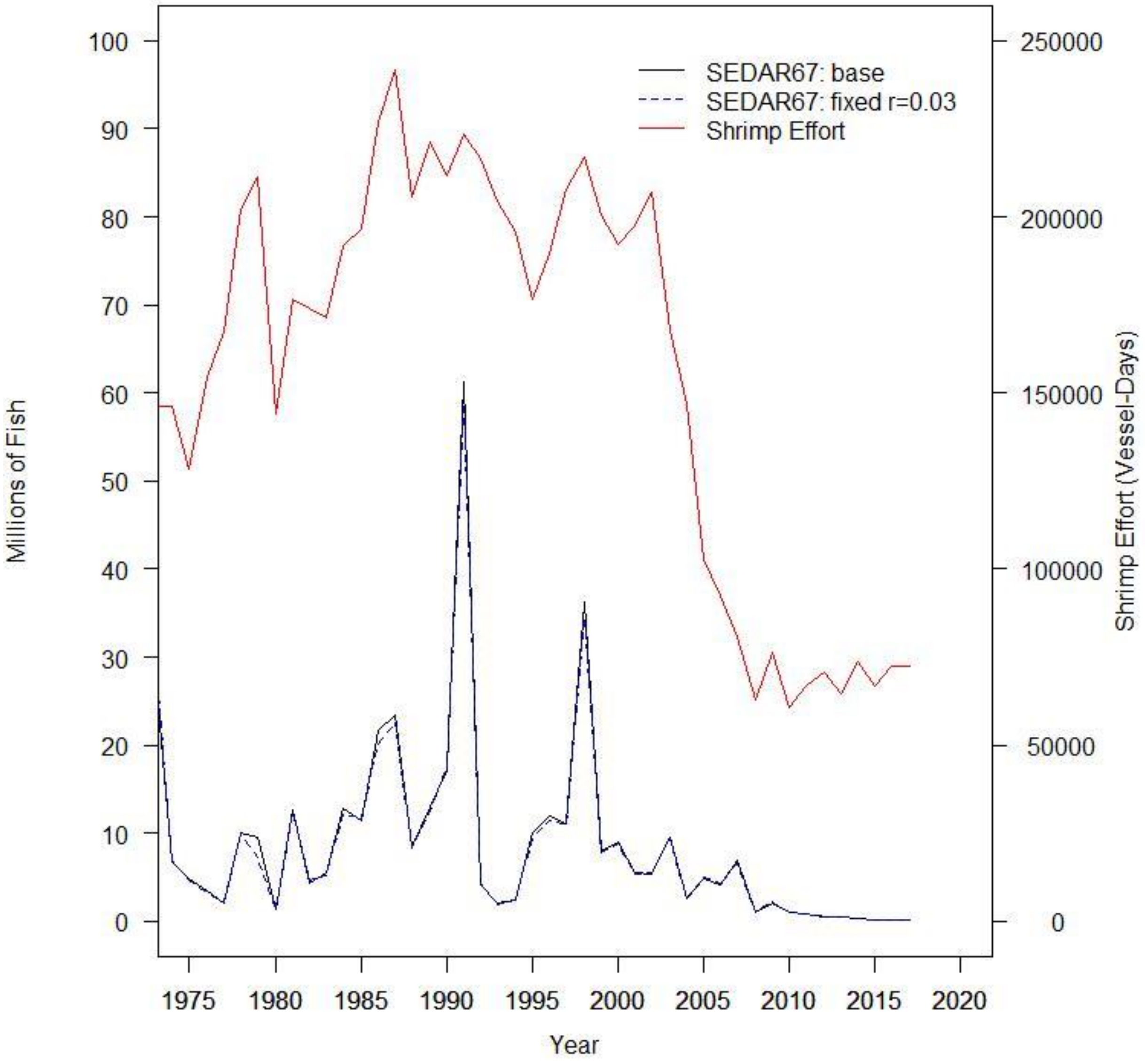


Figure 3. Annual bycatch (median) for vermilion snapper in the Gulf of Mexico shrimp fishery for the two SEDAR67 runs and shrimp fishery effort (vessel-days) provided by the NMFS Galveston Lab (calendar year).

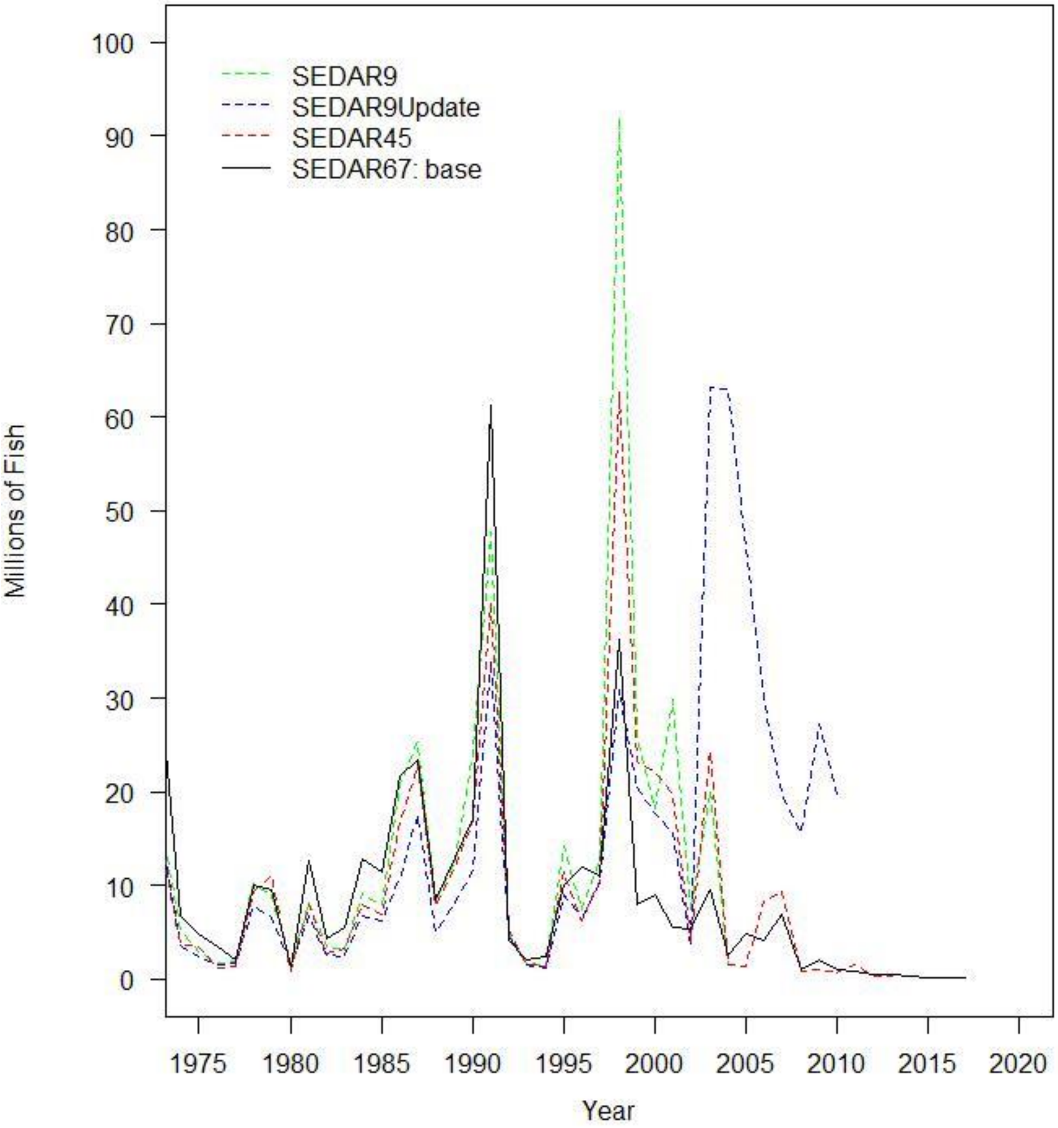


Figure 4. Annual bycatch (median) for vermilion snapper in the Gulf of Mexico shrimp fishery for the SEDAR 67 and previous SEDAR runs (calendar year).

Appendix. BUGS code for the 3-season, 4-area, 3-depth zone, 3-dataset (with BRD effect adjustment), error-in-effort and error-in-nets-per-vessel models used in SEDAR67 base and fixed r=0.03 runs.

SEADR67 base run (r~dunif(0.03,5); list(tau=0.5, r=0.15); list(tau=0.7, r=0.18))
SEDAR67 fixed r=0.03 run (r<-0.03; list(tau=0.5); list(tau=0.7))

```
model  GOM VS_3dp_3dset_h86343 1972-2017 (46 years) rsbycatch02 {

#Zhang need to update the endyr, and h_up with new data
#Zhang do GOM Vermilion Snapper: fishing year= calendar year
#Zhang season 1=Jan-Apr, season 2=May-Aug, season 3=Sept-Dec
#Zhang included BRD effect (see SEDAR7-DW-54 test and Appendix)
#Zhang report bycatch for only GOM, not need EGOM and WGOM

#Zhang Note from Nichols SEDAR7-DW3
#, but there were still numerical problems that caused the analyses to crash when using broad priors that allow
# the MCMC to explore very low values of r. There appeared to be two sources to the numerical crashes:
# 1) less frequently, a draw from the gamma with low r would produce a lambda numerical indistinguishable
# from zero by the computer, which crashed the Poisson portion of the routine, and 2) more frequently, the
# adaptive strategy (first 4000 iterations) for BUGS dropped the trial parameters for r to be extremely low
# level, and caused a numerical error even when the final posterior might not have been a problem. A solution
# for both problems was to constrain r with a 'hard-edged' prior that did not allow r below about 0.03. I chose to
# use a uniform prior on r (or r's in model 04) on the interval 0.03 to 5. For red snapper, this choice of prior
# appeared to have little impact on the r distributions ultimately chosen by the data, as the full range of the
# posteriors tended to be well above the 0.03 minimum. For king mackerel (Zhang: for vermilion snapper too),
# however, the shapes of the posteriors for the r's are clearly dominated by the lower bound of the prior

#Zhang for SEDAR67 base run
r~dunif(0.03,5)
#Zhang for SEDAR67 fixed r=0.03 run
# r<-0.03

tau~dlnorm(0,3.5)                       #Zhang local term or precision

#Zhang have this line in S31bycatch for RS 2dp but does NOT have this line S31bycatch for RS 3dp
#Zhang center was used in SEDAR7-DW-3 Model 02 and 03: logy with local term and predlogy with center
#Zhang center was still listed in SEDAR7-WD-54, but without predlogy and center NEVER was used
center~dnorm(0,tau)                     #Zhang, NEVER was used

for (i in 1:46)  {                      #Zhang 46 years, 1972-2017
  yx[i]~dnorm(-1,0.7)                    #Zhang VS year prior from SEDAR9AW3, NOT centered
  }
for (j in 1:3)  {                       #Zhang 3 seasons
  sraw[j]~dnorm(0,1)                    #Zhang season effect
  sx[j]<-sraw[j]-mean(sraw[])           #Zhang centered: deviation from the mean
  }
for (k in 1:4)  {                       #Zhang 4 areas
  araw[k]~dnorm(0,0.2)                  #Zhang area effect
  ax[k]<-araw[k]-mean(araw[])           #Zhang centered: deviation from the mean
  }
for (l in 1:3)  {                       #Zhang 3 depths
  zraw[l]~dnorm(0,0.2)                  #Zhang depth effect
  zx[l]<-zraw[l]-mean(zraw[])           #Zhang centered: deviation from the mean
  }
for (m in 1:3)  {                       #Zhang 3 datasets (separate BRD):  1=non-BRD, 2=Research, 3=BRD
  draw[m]~dnorm(0,1)                    #Zhang dataset effect
  dx[m]<-draw[m]-mean(draw[])           #Zhang centered: deviation from the mean
  }

#Zhang model main effects and local term
for (i in 1:46)  {                      #Zhang 46 years, 1972-2017, i
  for (j in 1:3)   {                    #Zhang 3 seasons, j
    for (k in 1:4)  {                   #Zhang 4 areas, k
      for (l in 1:3)  {                  #Zhang 3 depths, l
        for (m in 1:3)  {               #Zhang 3 datasets, m
```

```
          local[i,j,k,l,m]~dnorm(0,tau)

          logy[i,j,k,l,m]<-yx[i]+sx[j]+ax[k]+zx[l]+dx[m]+local[i,j,k,l,m]    #Zhang model ln(CPUE) with a local term
          y[i,j,k,l,m]<-exp(logy[i,j,k,l,m])
                #Zhang change ln(CPUE) to CPUE
          mu[i,j,k,l,m]<-r/y[i,j,k,l,m]
                                                  #Zhang shape r and mean mu for dgamma
          }
        }
      }
    }
  }

#Zhang update the total observations (i.e. h range) from SAS output e.g. VSBYCATCH_3DP_3DSET_1972_2017
#Zhang dgamma wih a shape parameter r and a mean parameter mu = r/y[i,j,k,l,m]
#Zhang Observed catch in number in each stratum was assumed to follow a negative binomial distribution,
#Zhang which was modeled as a conjugate gamma-Poisson distribution due to computational issues.
for (h in 1:86343) {                                              #Zhang need to update the end h
  lamb[h]~dgamma(r,mu[yr[h],seas[h],ar[h],dp[h],ds[h]])
  lambda[h]<-lamb[h]*hrsfishd[h]
  catch[h]~dpois(lambda[h])
  }

#Zhang take (i.e. bycatch) for 1972-1997 (i.e. i=1:26), prior mandatory BRD, use no-BRD_CPUE 1 (i.e. y[i,j,k,l,1])
for (i in 1:26)  {
  for (j in 1:3)   {
    for (k in 1:4)  {
      for (l in 1:3)  {

        effort[i,j,k,l]~dnorm(effmean[i,j,k,l],efftau[i,j,k,l])           #Zhang shrimp effort
        npv[i,j,k,l]~dnorm(voufmean[i],vouftau[i])                        #Zhang net per vessel
        take[i,j,k,l]<-y[i,j,k,l,1]*npv[i,j,k,l]*effort[i,j,k,l]          #Zhang take stands for estimated bycatch
        }
      }
    }
  }

#Zhang take (i.e. bycatch) for 1998 (i.e. i=27), phased in mandatory BRD year, HARD CODED
#Zhang season 1, all areas and depths use no-BRD_CPUE 1 (i.e. y[27,1,k,l,1])
    for (k in 1:4)  {
      for (l in 1:3)  {

        effort[27,1,k,l]~dnorm(effmean[27,1,k,l],efftau[27,1,k,l])
        npv[27,1,k,l]~dnorm(voufmean[27],vouftau[27])
        take[27,1,k,l]<-y[27,1,k,l,1]*npv[27,1,k,l]*effort[27,1,k,l]
        }
      }
#Zhang season 2, area 1 and all depths, use no-BRD_CPUE 1 (i.e. y[27,2,1,l,1])
      for (l in 1:3)  {
        effort[27,2,1,l]~dnorm(effmean[27,2,1,l],efftau[27,2,1,l])
        npv[27,2,1,l]~dnorm(voufmean[27],vouftau[27])
        take[27,2,1,l]<-y[27,2,1,l,1]*npv[27,2,1,l]*effort[27,2,1,l]
        }
#Zhang season 2, areas 2-4 all depths, use BRD_CPUE 3 (i.e. y[27,2,k,l,3])
     for (k in 2:4)  {

      for (l in 1:3)  {
        effort[27,2,k,l]~dnorm(effmean[27,2,k,l],efftau[27,2,k,l])
        npv[27,2,k,l]~dnorm(voufmean[27],vouftau[27])
        take[27,2,k,l]<-y[27,2,k,l,3]*npv[27,2,k,l]*effort[27,2,k,l]
        }
      }
#Zhang season 3, all areas and depths, use BRD_CPUE 3 (i.e. y[27,3,k,l,3])
    for (k in 1:4)  {
      for (l in 1:3)  {
        effort[27,3,k,l]~dnorm(effmean[27,3,k,l],efftau[27,3,k,l])
        npv[27,3,k,l]~dnorm(voufmean[27],vouftau[27])
        take[27,3,k,l]<-y[27,3,k,l,3]*npv[27,3,k,l]*effort[27,3,k,l]
        }
      }
```

```
#Zhang take (i.e. bycatch) for1999-2017 (i.e. i=28:46) mandatory BRD, use BRD CPUE 3 (i.e. y[i,j,k,l,3])
for (i in 28:46)  {                                    #Zhang need to update end year range
  for (j in 1:3)   {
    for (k in 1:4)  {
      for (l in 1:3)  {
        effort[i,j,k,l]~dnorm(effmean[i,j,k,l],efftau[i,j,k,l])
        npv[i,j,k,l]~dnorm(voufmean[i],vouftau[i])
        take[i,j,k,l]<-y[i,j,k,l,3]*npv[i,j,k,l]*effort[i,j,k,l]
        }
      }
    }
  }

#Zhang GOM,annual bycatch
for (i in 1:46) {                                      #Zhang need to update the end year
  annual[i]<-sum(take[i,,,])                           #Zhang sum season/area/depth specific annual
  loga[i]<-log(annual[i])                              #Zhang convert to log scale
 }

#Zhang East and West annual: not need for VS
#for (i in 1:46) {                                     #Zhang need to update the end year
#  annualE[i]  <-sum(take[i,,1:2,])                    #Zhang sum season/area/depth specific annual for Areas 1-2
#  annualW[i]<- sum(take[i,,3:4,])                     #Zhang sum season/area/depth specific annual for Areas 3-4
# }

#Zhang GOM do three seasons: not need for VS
#for (i in 1:46) {                                     #Zhang need to update the end year
#   for (j in 1:3)    {
#    trimester[i,j]<-sum(take[i,j,,])                  #Zhang season specific GOM annual
#   }
#}


#Zhang Gulfwise, East, West median of annual medium (i.e. mofam),; 46, so use average 23 and 24
mofam<-    (ranked(annual[1:46],23) + ranked(annual[1:46],24))/2
#mofamE<-  (ranked(annualE[1:46],23) + ranked(annualE[1:46],24))/2
#mofamW<- (ranked(annualW[1:46],23) + ranked(annualW[1:46],24))/2
}
#Zhang for SEDAR67 base run
list(tau=0.5, r=0.15)            #Zhang provide initial values for chain 1, WinBUGS can provide default
list(tau=0.7, r=0.18)            #Zhang provide initial values for chain 2, WinBUGS can provide default

#Zhang for SEDAR67 fixed r=0.03 run
#list(tau=0.5)                   #Zhang provide initial values for chain 1, WinBUGS can provide default
#list(tau=0.7)                   #Zhang provide initial values for chain 2, WinBUGS can provide default
```