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SEDAR62-WP-20

5 February 2020

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Please cite this document as:

Zhang, X.. 2020. Shrimp Fishery Bycatch Estimates for Gulf of Mexico Grey Triggerfish, 1972-2017. SEDAR62 WP-20. SEDAR, North Charleston, SC. 29 pp.

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1/15/2020

Summary

A WinBUGS Bayesian approach was developed by Nichols and was used in the SEDAR 7 Gulf of Mexico red snapper shrimp bycatch estimates in SEDAR7-DW-3 (Nichols 2004a). This model was then modified and incorporated the estimates of uncertainty for shrimping effort, included variable "nets per vessel" estimates and separated observer data into BRD and non-BRD datasets in SEDAR7-DW-54 (Nichols 2004b). This model was further modified by recommending species-specific prior choices for the year effects for red snapper, vermilion snapper, grey triggerfish, great amberjack, and king mackerel in SEDAR9-AW-3 (Nichols 2006). Although Nichols was able to use this model to evaluate the impact of BRDs for red snapper, estimates with BRDs could not be produced for triggerfish in SEDAR 9 (Nichols 2006). Grey triggerfish was not on the list of 22 species for which data were to be recorded during "Evaluation Protocol" observer trips and was not selected but instead placed in the other grouped finfish category during observer trips (Scott-Denton, personal communication). Hence, shrimp observer data relevant to grey triggerfish are very, very sparse. There was only a 2-year (2001 and 2002) overlap in the use/non-use of BRDs for GOM grey triggerfish from observer trips and *there are no new shrimp observer data since those available for SEDAR 9*. Therefore we retain Nichols' (2006) conclusion that "It is not possible to obtain an estimate for bycatch with BRDs for triggerfish with the Bayesian model". We did not try to evaluate the impact of BRDs and did not separate use/non-use of BRD data within the WinBUGS Bayesian bycatch model. However we proposed an approach to adjust the impact of BRDs for grey triggerfish using the information from vermilion snapper and king mackerel outside the WinBUGS Bayesian bycatch model. Shrimp bycatch estimates for the Gulf of Mexico grey triggerfish were generated using the same WinBUGS Bayesian approach developed for red snapper by Nichols, except for not separating use/non-use of BRD data. Estimates of shrimp fishery bycatch (median) for 1972-2017 ranged from 0.078-3.941, 0.121-7.496, and 0.449-20.260 million grey triggerfish in the eastern Gulf of Mexico, western Gulf of Mexico, and entire Gulf of Mexico, respectively. After adjusting for the impact of BRDs, estimates of shrimp fishery bycatch (median) for 1972-2017 ranged from

0.035-2.567, 0.075-5.419, and 0.198-15.030 million grey triggerfish in the eastern Gulf of Mexico, western Gulf of Mexico, and entire Gulf of Mexico, respectively.

Methods

A WinBUGS Bayesian approach was developed by Nichols and was used in the SEDAR 7 Gulf of Mexico red snapper shrimp bycatch estimates in SEDAR7-DW-3 (Nichols 2004a). This model was then modified and incorporated the estimates of uncertainty for shrimping effort, included variable "nets per vessel" estimates and separated observer data into BRD and non-BRD datasets in SEDAR7-DW-54 (Nichols 2004b). This model was further modified by recommending species-specific prior choices for the year effects for red snapper, vermilion snapper, grey triggerfish, great amberjack, and king mackerel in SEDAR9-AW-3 (Nichols 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 only a 2-year 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 vessels with non-BRD was larger than the CPUE from commercial vessels with BRD for these 2 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 SEAMAP Gulf trawl survey was larger than the CPUE from commercial vessels (Table 2). Because there were no observed shrimp tows after 2002 (Table 2), most of the spatial and annual commercial bycatch rate signals are driven by the SEAMAP survey for the most recent 15 years.

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 SEDAR 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 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 has the same form as the SEDAR 7 (Nichols 2004b) model updated with the SEDAR 9 recommended prior choice for year effect for grey triggerfish (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 $CPUE_{[i,j,k,l,m]}$ is estimated year/season/area/depth/dataset-specific CPUE, $year_{[i]}$, $season_{[j]}$, $area_{[k]}$, $depth_{[l]}$ and $dataset_{[m]}$ are the main effects, $local_{[i,j,k,l,m]}$ 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 values 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. However for the data-poor species grey triggerfish, the shapes of the posteriors for the r values of the conjugate gamma-Poisson distribution tended to be above the 0.03 minimum. 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 SEDAR7-DW-54 (Nichols 2004b). 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 to 1998: non-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 different 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, and all strata of post 1998 were assumed to be BRD strata. Although Nichols was able to use this model to evaluate the impact of BRDs for red snapper, estimates with BRDs could not be produced for triggerfish during SEDAR 9 (Nichols 2006). Grey triggerfish was not on the list of 22 species for which data were to be recorded during "Evaluation Protocol" observer trips and was not selected but instead placed in the other grouped finfish category during observer trips (Scott-Denton, personal communication). Hence, shrimp observer data relevant to grey triggerfish are very, very sparse. There was only a 2-year (2001 and 2002) overlap in the use/non-use of BRDs for GOM grey triggerfish from observer trips and *there are no new shrimp observer data since those available for SEDAR 9*. Therefore we retain Nichols' (2006) conclusion that "It is not possible to obtain an estimate for bycatch with BRDs for triggerfish with the Bayesian model". We did not try to evaluate the impact of BRDs and did not separate use/no-use of BRD data within the WinBUGS Bayesian bycatch model. However, we proposed an approach to adjust the impact of BRDs for grey triggerfish using the information from vermilion snapper and king mackerel outside the WinBUGS Bayesian bycatch model. Shrimp bycatch estimates for the Gulf of Mexico grey triggerfish were generated using the same WinBUGS Bayesian approach developed for red snapper by Nichols, except for not separating use/non-use of BRD data (see Appendix for WinBUGS code).

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 (median) for of 1972-2017 ranged from 0.078-3.941, 0.121-7.496, and 0.449-20.260 millions of grey triggerfish in the eastern Gulf of Mexico, western Gulf of Mexico, and entire Gulf of Mexico, respectively (Tables 7 and 8, Figure 3). The estimates of shrimp bycatch have very large confidence intervals in most years (Table 7). The statistics of marginal posterior densities of the grand median estimates of annual median estimates (1972-2017) of grey triggerfish bycatch (millions of fish) in the Gulf of Mexico shrimp fishery are reported in Table 8. Estimates of shrimp fishery bycatch from SEDAR 62 were similar to the previous SEDARs for the overlapping years (Table 9 and Figure 4). A lot of new data for king mackerel and vermilion snapper from the Observer program have been collected since those available for SEDAR 9. Combined with the lower observed bycatch rates most likely due to mandatory BRD requirements and lower shrimp effort, shrimp bycatch has been very low during the past 10-15 years for both the recent SEDAR 38 update for king mackerel and SEDAR 68 for vermilion snapper. Unfortunately, there are no new presumably lower bycatch rates from the Observer program for grey triggerfish since those available for SEDAR 9 to inform the model and reduce the grey triggerfish bycatch estimates. The ratio of the grand median of annual median estimates between the mandatory BRD requirements period (1989-2017) and the non-mandatory BRD requirements period (1972-1988) for grey triggerfish is 0.446, which is much higher than for vermilion snapper (0.209) and king mackerel (0.186) for the same time period which has incorporated BRD impacts (Table 10). Therefore, the grey triggerfish bycatch estimates for the recent years most likely are overestimated. The mean of ratios of grand medians during mandatory and non-mandatory BRD requirements for vermilion snapper and king mackerel is 0.197. To decrease the ratio of the grand median of annual median estimates between the mandatory BRD requirements period (1989-2017) and the non-mandatory BRD requirements period (1972-1988) for grey triggerfish from 0.446 to 0.197, we need to multiply 0.423 (here we call it the GOM BRD adjustment factor for grey triggerfish during mandatory BRD requirements) by SEDAR 62 grey triggerfish values for 1989-2017 (Table 10 and Figure 5). As the SEDAR 62 Panel has decided to separate eastern GOM and western GOM, we assumed that the GOM BRD adjustment factor for grey triggerfish (0.423) is applicable to the eastern GOM and western GOM estimates. We adjusted SEDAR 62 grey triggerfish values for 1989-2017 by multiplying the BRD adjustment factor for grey triggerfish during mandatory BRD requirements (1999-2007) (0.423) by SEDAR 62 grey triggerfish values for 1989-2017. After adjusting for the impact of BRDs, estimates of shrimp fishery bycatch (median) for 1972-2017 ranged from 0.035-2.567, 0.075-5.419, and 0.198-15.030 millions of grey triggerfish in the eastern Gulf of Mexico, western Gulf of Mexico, and entire Gulf of Mexico, respectively (Table 11 and Figure 6) (*note: we may need to estimate vermilion snapper and king mackerel for eastern GOM and western GOM separately if the Panel like this approach*).

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. Unfortunately, grey triggerfish was not on the list of 22 species for which data were to be recorded during "Evaluation Protocol" observer trips. Grey triggerfish was not selected but instead placed in the other grouped finfish category during observer trips. Hence, shrimp observer data relevant to grey triggerfish are very, very sparse. There was only a 2-year (2001 and 2002) overlap in the use/non-use of BRDs for GOM grey triggerfish from observer trips and *there are no new shrimp observer data since those available for SEDAR 9*. Most of the spatial and annual bycatch rate signals are driven by the SEAMAP survey for the most recent 15 years. To get accurate GOM grey triggerfish shrimp bycatch estimates for stock assessments, shrimp bycatch of this species needs to be selected and recorded at the species level instead of placed in the other grouped finfish category during observer trips.

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). I wish to thank Enric Cortes for his helpful comments which improved this report.

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Table 1. Datasets used in the estimation of shrimp bycatch CPUE 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 non-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 effort (CPUE) from datasets of commercial vessels with non-BRD, commercial vessels with BRD, and research vessel Oregon II SEAMAP Gulf trawl survey in the Gulf of Mexico.

	Tows			Percentage positive			CPUE (fish/net-hour)		
Year	BRD	non-BRD	SEAMAP-GOM	BRD	non-BRD	SEAMAP-GOM	BRD	non-BRD	SEAMAP-GOM
1972		10	633		0.00%	8.21%		0.000	1.477
1973		81	1136		0.00%	6.34%		0.000	1.257
1974		80	1933		1.25%	4.76%		0.013	0.992
1975		175	1702		1.14%	1.82%		0.025	1.036
1976		315	1631		0.95%	1.53%		0.101	0.205
1977		263	1298		4.56%	5.01%		0.322	1.193
1978		266	1098		8.27%	7.56%		0.411	1.627
1979		1	745		0.00%	4.16%		0.000	0.443
1980		296	1479		8.78%	3.72%		0.609	0.592
1981		192	1546		5.21%	4.59%		0.472	0.843
1982		56	1496		5.36%	3.81%		0.477	0.524
1983			1180			3.90%			0.389
1984			1454			2.82%			0.367
1985			661			3.48%			0.295
1986			434			11.29%			1.209
1987			395			14.94%			1.074
1988			418			14.35%			1.556
1989			420			19.52%			1.745
1990			492			11.79%			0.763
1991			487			29.77%			4.463
1992		488	476		13.32%	10.50%		0.188	0.587
1993		563	500		22.74%	20.80%		0.546	2.613
1994		279	477		6.09%	27.25%		0.091	2.752
1995			435			22.53%			1.752
1996			464			14.01%			1.161
1997			434			17.05%			1.161
1998			387			5.17%			0.204
1999			509			22.00%			2.784
2000			491			29.53%			4.467
2001	17	6	355	41.18%	100.00%	33.80%	0.604	6.112	7.334
2002	393	89	469	5.60%	8.99%	21.32%	0.069	0.137	1.665
2003			422			13.74%			1.260
2004			413			18.40%			0.987
2005			233			17.60%			0.632
2006			385			19.74%			4.159
2007			422			18.72%			1.387
2008			553			25.50%			1.292
2009			622			10.93%			0.359
2010			411			10.71%			0.890
2011			331			19.34%			1.544
2012			369			23.31%			2.982
2013			222			12.61%			0.808
2014			380			14.74%			1.007
2015			382			21.20%			1.313
2016			405			8.64%			0.325
2017			385			16.36%			0.863
Totals or Averages	410	3160	31570	7.07%	9.59%	10.17%	0.091	0.317	1.222

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 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).

	Eastern GOM		Western GOM		GOM_Effort	
Year	Effort	SE	Effort	SE	Effort	SE
1972	33449	121	123746	415	157194	433
1973	36229	143	109861	473	146089	494
1974	35714	142	110701	431	146415	454
1975	35308	129	93212	305	128520	331
1976	32221	122	122254	507	154475	521
1977	42531	162	125020	597	167552	618
1978	35168	146	166834	1065	202002	1075
1979	33728	121	177769	1672	211497	1677
1980	21249	79	123007	866	144256	870
1981	36067	170	140659	352	176727	391
1982	34212	149	139681	398	173894	425
1983	40298	236	131012	532	171311	582
1984	50592	184	141218	541	191810	572
1985	44017	168	152612	467	196628	497
1986	40896	167	185902	590	226798	613
1987	35722	181	206181	771	241902	792
1988	37366	188	168446	634	205812	662
1989	43230	259	178010	772	221240	815
1990	38730	295	173195	733	211924	790
1991	33811	182	189578	753	223388	775
1992	37674	260	178994	728	216669	774
1993	31361	166	173121	766	204482	784
1994	36101	200	159641	917	195742	939
1995	42802	228	133787	577	176589	620
1996	47497	244	142327	625	189824	671
1997	47546	244	160366	672	207912	715
1998	57747	314	159251	760	216999	822
1999	38401	224	162073	711	200475	745
2000	32274	158	159799	708	192073	725
2001	33986	171	163659	796	197644	814
2002	41099	287	165703	950	206802	992
2003	33168	214	134967	603	168135	640
2004	30473	210	116151	431	146624	479
2005	24632	126	78207	345	102840	368
2006	18032	72	74340	266	92372	276
2007	15580	58	65153	234	80733	241
2008	13110	598	49687	142	62797	615
2009	17527	77	58981	170	76508	187
2010	9248	52	51271	160	60518	168
2011	11560	48	55217	159	66777	166
2012	12113	49	58392	195	70505	201
2013	12635	95	52194	193	64828	216
2014	10167	44	63515	278	73683	282
2015	11459	57	55390	220	66849	227
2016	11968	56	60641	209	72609	216
2017	12470	56	60070	203	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.
Note: Eastern GOM = Area 1 and Area 2, Western GOM = Area 3 and Area 4.

Main Effect	Levels	Description
Year	46	1972-2017 Note: Prior 1998: non-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	2	Dataset 1 (Observer non-BRD and BRD) Dataset 2 (Research vessel)

*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) of grey triggerfish bycatch (millions of fish) in the eastern Gulf of Mexico shrimp fishery (calendar year). Note: as these estimates (either Mean or Median) are numerical (not analytical) solutions with uncertainty, the sum of the eastern GOM and western GOM estimates is not equal to the estimates for the entire GOM.

Year	Mean	SD	MC error	2.50%	Median	97.50%
1972	1.717	2.084	0.062	0.222	1.116	6.822
1973	0.761	1.153	0.025	0.119	0.493	3.090
1974	0.631	0.883	0.023	0.108	0.430	2.358
1975	0.383	0.747	0.014	0.069	0.244	1.456
1976	0.126	0.161	0.003	0.022	0.085	0.464
1977	0.746	0.603	0.011	0.227	0.601	2.121
1978	0.419	0.438	0.010	0.117	0.314	1.350
1979	0.747	0.942	0.031	0.079	0.455	3.299
1980	0.439	0.378	0.009	0.132	0.348	1.292
1981	0.638	0.791	0.017	0.132	0.438	2.392
1982	0.877	1.169	0.026	0.139	0.563	3.529
1983	0.541	0.723	0.017	0.087	0.359	2.059
1984	0.508	0.650	0.015	0.082	0.334	1.975
1985	0.411	0.494	0.011	0.064	0.279	1.531
1986	1.270	2.006	0.038	0.190	0.802	5.099
1987	1.464	1.767	0.040	0.200	0.947	5.702
1988	0.825	1.082	0.020	0.120	0.535	3.302
1989	2.014	2.801	0.059	0.265	1.285	8.184
1990	0.771	0.952	0.020	0.112	0.509	3.066
1991	3.943	5.312	0.102	0.567	2.567	15.490
1992	1.258	1.517	0.029	0.211	0.835	4.802
1993	0.930	0.689	0.012	0.390	0.745	2.599
1994	0.767	1.224	0.022	0.137	0.479	3.017
1995	3.099	3.997	0.097	0.446	1.988	12.810
1996	3.109	4.219	0.090	0.432	1.967	12.700
1997	1.803	2.594	0.050	0.248	1.187	6.851
1998	0.687	1.091	0.021	0.087	0.414	2.851
1999	2.448	3.096	0.063	0.374	1.600	9.944
2000	3.466	4.205	0.103	0.511	2.312	12.930
2001	6.076	8.127	0.176	0.842	3.941	23.280
2002	0.767	0.953	0.019	0.236	0.536	2.610
2003	1.259	1.877	0.038	0.160	0.777	5.131
2004	1.162	2.913	0.046	0.142	0.670	4.925
2005	0.897	1.597	0.031	0.098	0.506	3.813
2006	0.892	1.111	0.029	0.134	0.584	3.596
2007	0.332	0.401	0.009	0.057	0.226	1.211
2008	0.377	0.512	0.011	0.064	0.260	1.314
2009	0.362	0.416	0.009	0.059	0.247	1.384
2010	0.357	0.461	0.011	0.051	0.228	1.495
2011	0.500	0.749	0.014	0.072	0.329	1.917
2012	0.571	0.830	0.017	0.091	0.376	2.157
2013	0.293	0.398	0.008	0.036	0.183	1.210
2014	0.288	0.397	0.008	0.048	0.197	1.070
2015	0.343	0.555	0.012	0.050	0.220	1.380
2016	0.116	0.139	0.003	0.018	0.078	0.419
2017	0.418	0.592	0.014	0.065	0.272	1.636

Table 7B. Statistics of marginal posterior densities of annual estimates (median) of grey triggerfish bycatch (millions of fish) in the western Gulf of Mexico shrimp fishery (calendar year). Note: as these estimates (either Mean or Median) are numerical (not analytical) solutions with uncertainty, the sum of the eastern GOM and western GOM estimates is not equal to the estimates for the entire GOM.

Year	Mean	SD	MC error	2.50%	Median	97.50%
1972	3.028	4.460	0.108	0.388	1.858	12.740
1973	0.671	0.704	0.017	0.149	0.496	2.199
1974	0.716	0.848	0.025	0.153	0.530	2.395
1975	0.622	1.327	0.024	0.105	0.373	2.487
1976	0.140	0.085	0.002	0.056	0.121	0.338
1977	0.755	0.566	0.010	0.248	0.622	1.961
1978	2.050	1.270	0.025	0.829	1.779	4.821
1979	1.535	2.092	0.067	0.169	0.956	6.297
1980	1.339	0.807	0.018	0.511	1.144	3.310
1981	2.346	1.277	0.025	0.978	2.018	5.787
1982	2.055	1.504	0.034	0.705	1.715	5.334
1983	0.869	1.037	0.026	0.151	0.604	3.134
1984	0.914	1.217	0.028	0.144	0.600	3.561
1985	0.674	0.767	0.018	0.110	0.465	2.573
1986	2.113	2.568	0.061	0.352	1.414	7.858
1987	2.869	4.614	0.088	0.394	1.920	10.680
1988	1.830	2.480	0.045	0.257	1.197	7.240
1989	3.543	4.428	0.090	0.518	2.349	13.950
1990	1.603	2.235	0.041	0.239	1.027	6.352
1991	8.216	10.530	0.199	1.247	5.419	31.720
1992	2.227	1.425	0.025	0.953	1.865	5.635
1993	1.406	0.915	0.016	0.574	1.158	3.879
1994	1.362	1.610	0.030	0.351	0.981	4.522
1995	4.902	6.049	0.143	0.756	3.258	18.900
1996	4.751	6.687	0.122	0.743	3.147	18.410
1997	3.022	3.605	0.081	0.469	2.039	11.740
1998	0.985	1.158	0.025	0.143	0.660	3.933
1999	3.975	4.317	0.093	0.692	2.759	14.990
2000	7.411	10.260	0.225	1.159	4.764	29.410
2001	11.270	13.770	0.288	1.608	7.496	44.220
2002	2.706	3.791	0.071	0.424	1.706	11.080
2003	2.893	3.559	0.063	0.414	1.839	12.250
2004	2.145	2.760	0.055	0.313	1.382	8.753
2005	1.512	2.380	0.043	0.197	0.950	6.090
2006	1.607	1.869	0.046	0.252	1.095	6.221
2007	0.681	0.732	0.015	0.122	0.476	2.466
2008	0.796	0.929	0.019	0.145	0.562	2.828
2009	0.693	0.796	0.017	0.123	0.483	2.418
2010	0.553	0.622	0.016	0.092	0.383	2.067
2011	1.056	1.345	0.029	0.155	0.692	4.094
2012	1.154	1.385	0.030	0.193	0.796	4.252
2013	0.570	0.744	0.015	0.079	0.368	2.221
2014	0.698	0.974	0.019	0.113	0.472	2.704
2015	0.820	1.254	0.030	0.121	0.548	3.175
2016	0.250	0.302	0.007	0.039	0.170	0.916
2017	0.788	0.953	0.023	0.132	0.537	2.964

Table 7C. Statistics of marginal posterior densities of annual estimates (median) of grey triggerfish bycatch (millions of fish) in the Gulf of Mexico shrimp fishery (calendar year). Note: as these estimates (either Mean or Median) are numerical (not analytical) solutions with uncertainty, the sum of the eastern GOM and western GOM estimates is not equal to the estimates for the entire GOM.

Year	Mean	SD	MC error	2.50%	Median	97.50%
1972	7.580	8.919	0.261	1.165	5.050	30.120
1973	1.845	1.860	0.048	0.465	1.401	5.653
1974	1.900	1.698	0.063	0.477	1.452	5.910
1975	1.474	1.923	0.044	0.320	1.031	5.287
1976	0.710	0.311	0.007	0.339	0.644	1.486
1977	1.911	0.960	0.019	0.868	1.692	4.253
1978	5.751	2.882	0.062	2.659	5.102	12.850
1979	3.573	3.879	0.151	0.528	2.509	12.900
1980	4.488	1.303	0.032	2.646	4.270	7.488
1981	5.299	6.359	0.112	1.840	4.188	14.800
1982	5.417	5.267	0.131	1.582	4.177	16.780
1983	2.504	2.489	0.072	0.531	1.851	8.619
1984	2.669	2.590	0.079	0.573	1.966	8.911
1985	1.891	1.917	0.050	0.378	1.383	6.512
1986	5.388	5.356	0.131	1.071	3.930	19.110
1987	7.235	7.887	0.187	1.286	5.223	24.910
1988	4.478	5.063	0.101	0.849	3.141	16.100
1989	8.719	9.176	0.215	1.674	6.190	32.800
1990	4.397	6.115	0.120	0.806	3.037	15.360
1991	20.710	20.300	0.441	3.879	15.030	73.970
1992	3.710	2.015	0.041	1.896	3.245	8.235
1993	7.394	2.228	0.034	4.432	6.978	12.570
1994	6.421	7.113	0.134	1.701	4.634	22.370
1995	12.720	13.140	0.349	2.684	9.258	42.650
1996	12.870	12.410	0.316	2.679	9.544	42.250
1997	8.192	8.959	0.196	1.605	5.942	28.220
1998	2.578	2.595	0.059	0.478	1.853	9.299
1999	10.390	10.060	0.233	2.110	7.595	34.860
2000	18.990	20.630	0.524	3.662	13.290	68.380
2001	28.660	37.210	0.702	5.772	20.260	100.400
2002	6.261	7.410	0.171	1.415	4.371	21.830
2003	6.776	6.728	0.139	1.323	4.878	23.880
2004	5.425	6.019	0.132	1.066	3.870	19.270
2005	3.489	3.872	0.094	0.582	2.432	13.000
2006	4.091	5.557	0.126	0.739	2.888	14.730
2007	1.895	2.022	0.047	0.383	1.375	6.509
2008	2.161	2.046	0.047	0.474	1.621	7.124
2009	1.889	1.824	0.042	0.401	1.394	6.477
2010	1.455	1.657	0.041	0.287	1.054	5.095
2011	2.552	3.305	0.064	0.458	1.752	9.053
2012	3.337	4.045	0.087	0.652	2.359	11.490
2013	1.424	1.688	0.041	0.233	0.981	5.415
2014	1.801	2.451	0.046	0.332	1.238	6.269
2015	2.241	2.920	0.066	0.388	1.505	8.246
2016	0.657	0.914	0.019	0.119	0.449	2.397
2017	1.797	1.948	0.049	0.368	1.277	6.211

Table 8. Statistics of marginal posterior densities of the grand median of annual median estimates (1972-2017) of grey triggerfish bycatch (millions of fish) in the Gulf of Mexico shrimp fishery. Note: as these estimates (either Mean or Median) are numerical (not analytical) solutions with uncertainty, the sum of the eastern GOM and western GOM estimates is not equal to the estimates for the entire GOM.

Region	Mean	SD	MC error	2.50%	Median	97.50%
Eastern GOM Not Evaluate BRD	0.518	0.126	0.006	0.316	0.500	0.797
Western GOM Not Evaluate BRD	1.073	0.235	0.011	0.667	1.054	1.595
GOM Not Evaluate BRD	3.053	0.645	0.030	1.932	2.995	4.497

Table 9. Annual bycatch (median in millions of fish) of grey triggerfish in the Gulf of Mexico shrimp fishery for the SEDAR 62 and previous SEDAR runs (calendar year).

Year	SEDAR9: GOM	SEDAR 9 Update: GOM	SEDAR 43: GOM	SEDAR 62: GOM
1972	3.479	3.735	3.083	5.050
1973	1.321	1.369	1.206	1.401
1974	1.576	1.712	1.535	1.452
1975	1.003	1.115	0.972	1.031
1976	0.809	0.806	0.744	0.644
1977	1.795	1.857	1.697	1.692
1978	6.776	6.669	6.248	5.102
1979	3.126	3.047	2.569	2.509
1980	5.725	5.940	5.423	4.270
1981	5.190	5.138	4.628	4.188
1982	6.009	5.554	5.120	4.177
1983	1.858	1.841	1.618	1.851
1984	3.312	3.562	3.116	1.966
1985	1.460	1.486	1.305	1.383
1986	3.999	3.849	3.537	3.930
1987	5.564	5.409	4.665	5.223
1988	4.029	4.407	3.615	3.141
1989	5.208	4.945	4.402	6.190
1990	2.576	2.441	2.219	3.037
1991	11.720	11.780	10.550	15.030
1992	3.148	3.190	2.967	3.245
1993	7.429	7.174	6.889	6.978
1994	4.912	4.314	4.059	4.634
1995	6.070	5.831	5.395	9.258
1996	7.223	7.356	6.037	9.544
1997	4.586	4.348	3.790	5.942
1998	1.399	1.327	1.096	1.853
1999	6.240	6.674	5.704	7.595
2000	2.640	13.540	11.680	13.290
2001	19.150	13.720	12.570	20.260
2002	5.717	3.279	3.113	4.371
2003	1.045	3.991	3.478	4.878
2004	0.120	3.160	2.755	3.870
2005		1.898	1.853	2.432
2006		3.275	3.054	2.888
2007		4.669	1.505	1.375
2008		14.280	1.239	1.621
2009		1.292	1.143	1.394
2010		3.171	1.239	1.054
2011			2.078	1.752
2012			2.545	2.359
2013			1.917	0.981
2014				1.238
2015				1.505
2016				0.449
2017				1.277

Table 10. Annual bycatch (median in millions of fish) of grey triggerfish (SEDAR 62), vermilion snapper (SEDAR 67) and king mackerel (SEDAR 38 Update) in the Gulf of Mexico shrimp fishery for 1972-2017 (calendar year). Adjusted SEDAR 62 GT values for 1989-2017 are obtained by multiplying the BRD adjustment factor for grey triggerfish during mandatory BRD requirements (1999-2007) (0.423) by SEDAR 62 GT values for 1989-2017.

Year	SEDAR62 GT: GOM	SEDAR 67 VS: GOM	SEDAR 38 Update KM: GOM		Adjusted SEDAR 62 GT: GOM
1972	5.050	43.450	15.570		5.050
1973	1.401	28.340	0.526		1.401
1974	1.452	6.814	1.890		1.452
1975	1.031	4.828	0.684		1.031
1976	0.644	3.505	0.867		0.644
1977	1.692	2.110	0.195		1.692
1978	5.102	10.090	2.153		5.102
1979	2.509	9.445	13.320		2.509
1980	4.270	1.442	0.170		4.270
1981	4.188	12.630	0.882		4.188
1982	4.177	4.254	1.095		4.177
1983	1.851	5.555	1.004		1.851
1984	1.966	12.770	3.880		1.966
1985	1.383	11.430	2.533		1.383
1986	3.930	21.760	3.302		3.930
1987	5.223	23.390	7.214		5.223
1988	3.141	8.487	4.539		3.141
1989	6.190	12.920	12.020		6.190
1990	3.037	17.150	9.847		3.037
1991	15.030	61.300	11.200		15.030
1992	3.245	4.194	1.136		3.245
1993	6.978	2.023	4.073		6.978
1994	4.634	2.439	2.508		4.634
1995	9.258	9.974	6.981		9.258
1996	9.544	11.910	2.665		9.544
1997	5.942	11.070	6.097		5.942
1998	1.853	36.260	1.928		1.853
1999	7.595	7.996	4.722		3.355
2000	13.290	8.949	5.816		5.870
2001	20.260	5.545	0.393		8.949
2002	4.371	5.394	0.378		1.931
2003	4.878	9.549	2.315		2.155
2004	3.870	2.561	4.861		1.709
2005	2.432	4.778	2.647		1.074
2006	2.888	4.189	2.201		1.276
2007	1.375	6.844	0.938		0.607
2008	1.621	1.038	0.442		0.716
2009	1.394	2.106	0.259		0.616
2010	1.054	1.111	0.374		0.466
2011	1.752	0.852	0.153		0.774
2012	2.359	0.443	0.113		1.042
2013	0.981	0.574	0.706		0.433
2014	1.238	0.291	0.059		0.547
2015	1.505	0.179	0.505		0.665
2016	0.449	0.155	0.471		0.198
2017	1.277	0.212	0.391		0.564
Grand median during non-mandatory BRD requirements (1972-1998)	3.930	10.090	2.533		3.930
Grand median during mandatory BRD requirements (1999-2017)	1.752	2.106	0.471		0.774
Ratio of grand medians during mandatory and non-mandatory BRD requirements	0.446	0.209	0.186		0.197

Mean of ratios of grand medians during mandatory and non-mandatory BRD requirements for vermilion snapper and king mackerel = 0.197 (i.e. (0.209 + 0.186)/2)

BRD adjustment factor for grey triggerfish during mandatory BRD requirements (1999-2007) = 0.423 (i.e 0.197/0.446)

Table 11. Annual bycatch (median in millions of fish) of grey triggerfish in the Gulf of Mexico shrimp fishery for 1972-2017 (calendar year). Adjusted SEDAR 62 values for 1989-2017 are obtained by multiplying the BRD adjustment factor for grey triggerfish during mandatory BRD requirements (1999-2007) (0.423) by SEDAR 62 values for 1989-2017 (see Table 10 for details).

Year	SEDAR62: EGOM	SEDAR62: WGOM	SEDAR62: GOM		Adjusted SEDAR 62: EGOM	Adjusted SEDAR 62: WGOM	Adjusted SEDAR 62: GOM
1972	1.116	1.858	5.050		1.116	1.858	5.050
1973	0.493	0.496	1.401		0.493	0.496	1.401
1974	0.430	0.530	1.452		0.430	0.530	1.452
1975	0.244	0.373	1.031		0.244	0.373	1.031
1976	0.085	0.121	0.644		0.085	0.121	0.644
1977	0.601	0.622	1.692		0.601	0.622	1.692
1978	0.314	1.779	5.102		0.314	1.779	5.102
1979	0.455	0.956	2.509		0.455	0.956	2.509
1980	0.348	1.144	4.270		0.348	1.144	4.270
1981	0.438	2.018	4.188		0.438	2.018	4.188
1982	0.563	1.715	4.177		0.563	1.715	4.177
1983	0.359	0.604	1.851		0.359	0.604	1.851
1984	0.334	0.600	1.966		0.334	0.600	1.966
1985	0.279	0.465	1.383		0.279	0.465	1.383
1986	0.802	1.414	3.930		0.802	1.414	3.930
1987	0.947	1.920	5.223		0.947	1.920	5.223
1988	0.535	1.197	3.141		0.535	1.197	3.141
1989	1.285	2.349	6.190		1.285	2.349	6.190
1990	0.509	1.027	3.037		0.509	1.027	3.037
1991	2.567	5.419	15.030		2.567	5.419	15.030
1992	0.835	1.865	3.245		0.835	1.865	3.245
1993	0.745	1.158	6.978		0.745	1.158	6.978
1994	0.479	0.981	4.634		0.479	0.981	4.634
1995	1.988	3.258	9.258		1.988	3.258	9.258
1996	1.967	3.147	9.544		1.967	3.147	9.544
1997	1.187	2.039	5.942		1.187	2.039	5.942
1998	0.414	0.660	1.853		0.414	0.660	1.853
1999	1.600	2.759	7.595		0.707	1.219	3.355
2000	2.312	4.764	13.290		1.021	2.104	5.870
2001	3.941	7.496	20.260		1.741	3.311	8.949
2002	0.536	1.706	4.371		0.237	0.754	1.931
2003	0.777	1.839	4.878		0.343	0.812	2.155
2004	0.670	1.382	3.870		0.296	0.610	1.709
2005	0.506	0.950	2.432		0.223	0.419	1.074
2006	0.584	1.095	2.888		0.258	0.484	1.276
2007	0.226	0.476	1.375		0.100	0.210	0.607
2008	0.260	0.562	1.621		0.115	0.248	0.716
2009	0.247	0.483	1.394		0.109	0.213	0.616
2010	0.228	0.383	1.054		0.101	0.169	0.466
2011	0.329	0.692	1.752		0.145	0.305	0.774
2012	0.376	0.796	2.359		0.166	0.351	1.042
2013	0.183	0.368	0.981		0.081	0.163	0.433
2014	0.197	0.472	1.238		0.087	0.208	0.547
2015	0.220	0.548	1.505		0.097	0.242	0.665
2016	0.078	0.170	0.449		0.035	0.075	0.198
2017	0.272	0.537	1.277		0.120	0.237	0.564

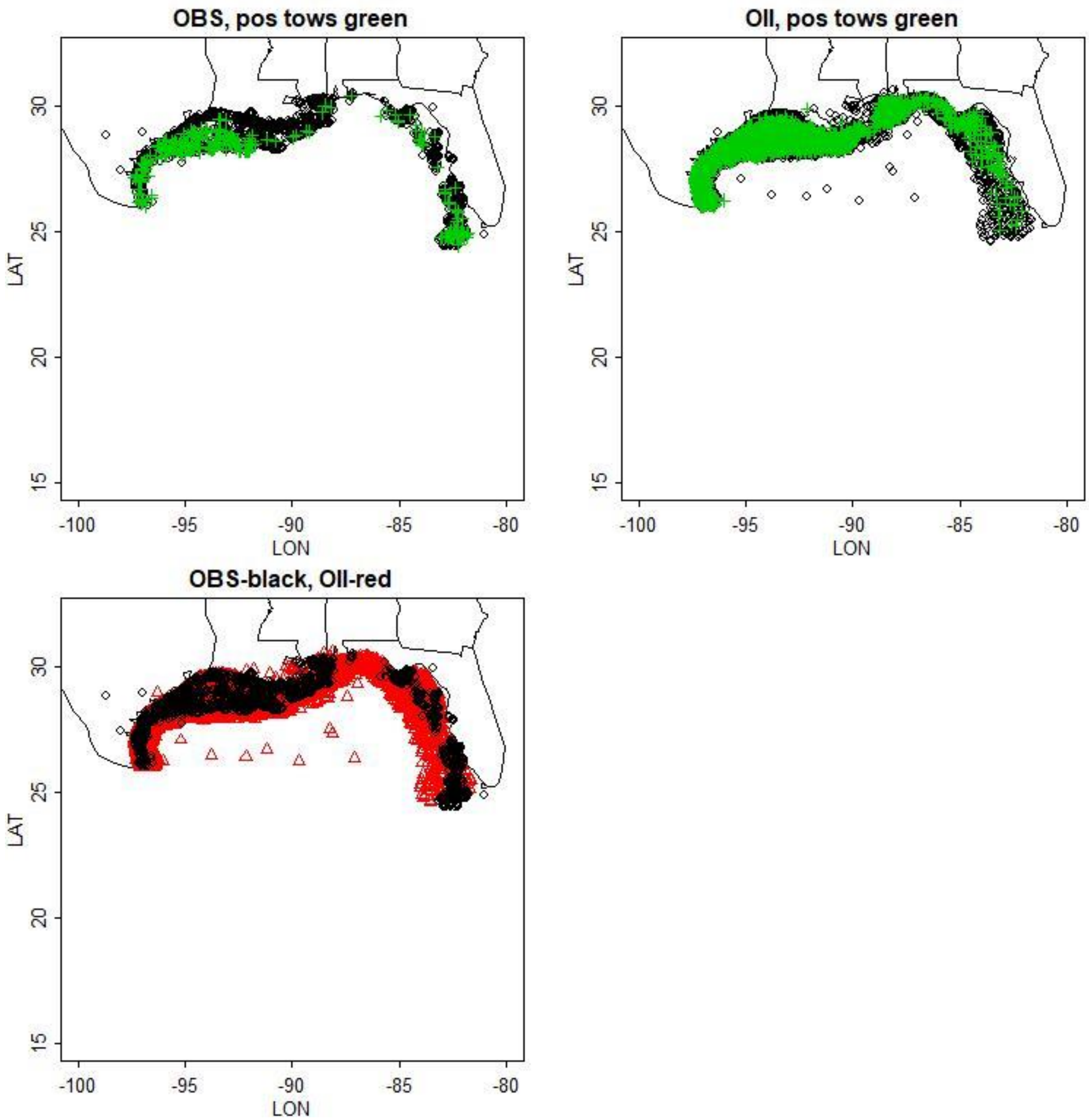

Figure 1. Spatial plots of shrimp observer data and Oregon II SEAMAP data with positive tows shown in green and overlap of Oregon II SEAMAP (red) and Observer (black).

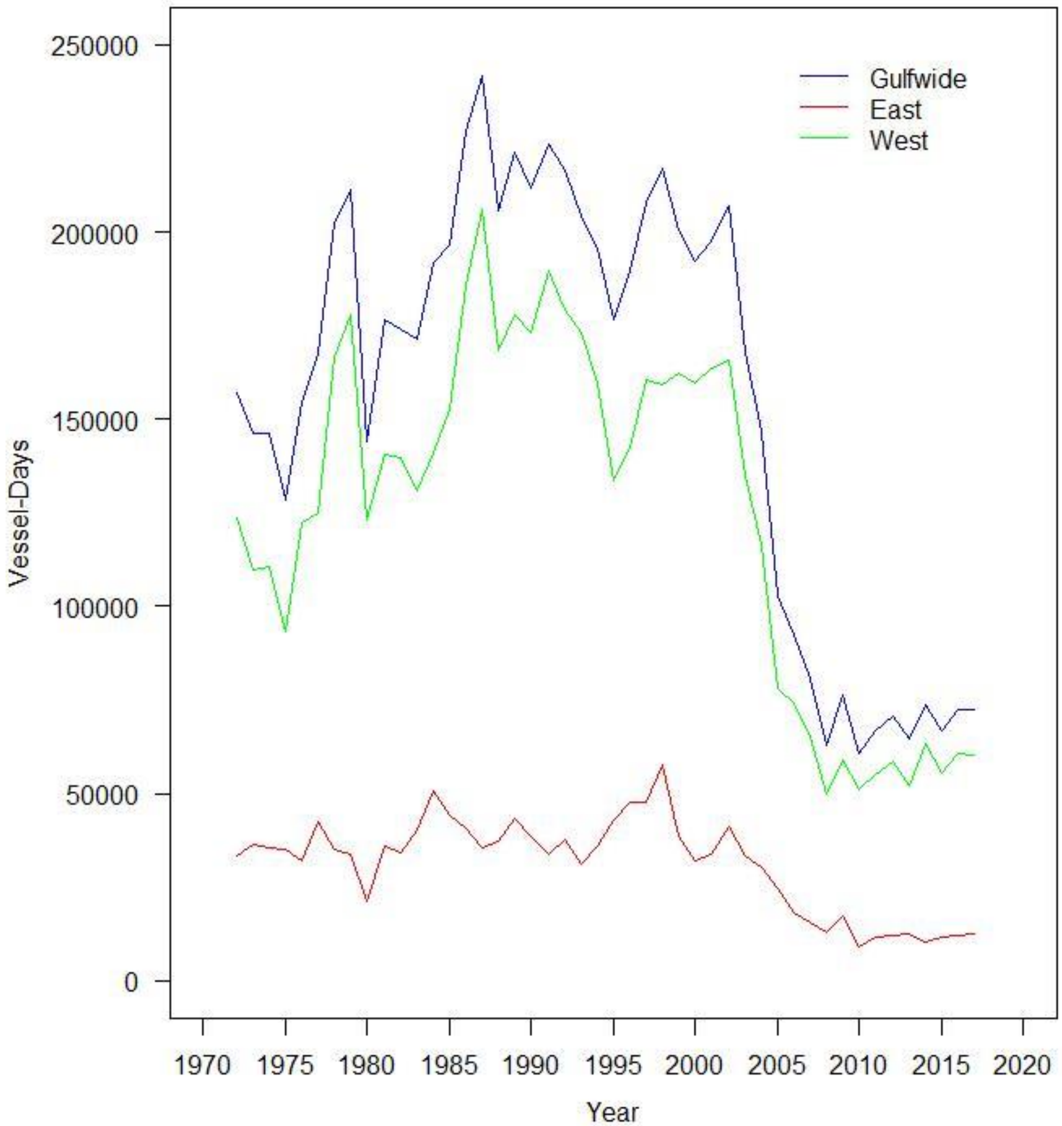

Figure 2. Gulf of Mexico shrimp fishery effort (vessel-days) provided by the NMFS Galveston Lab (calendar year).

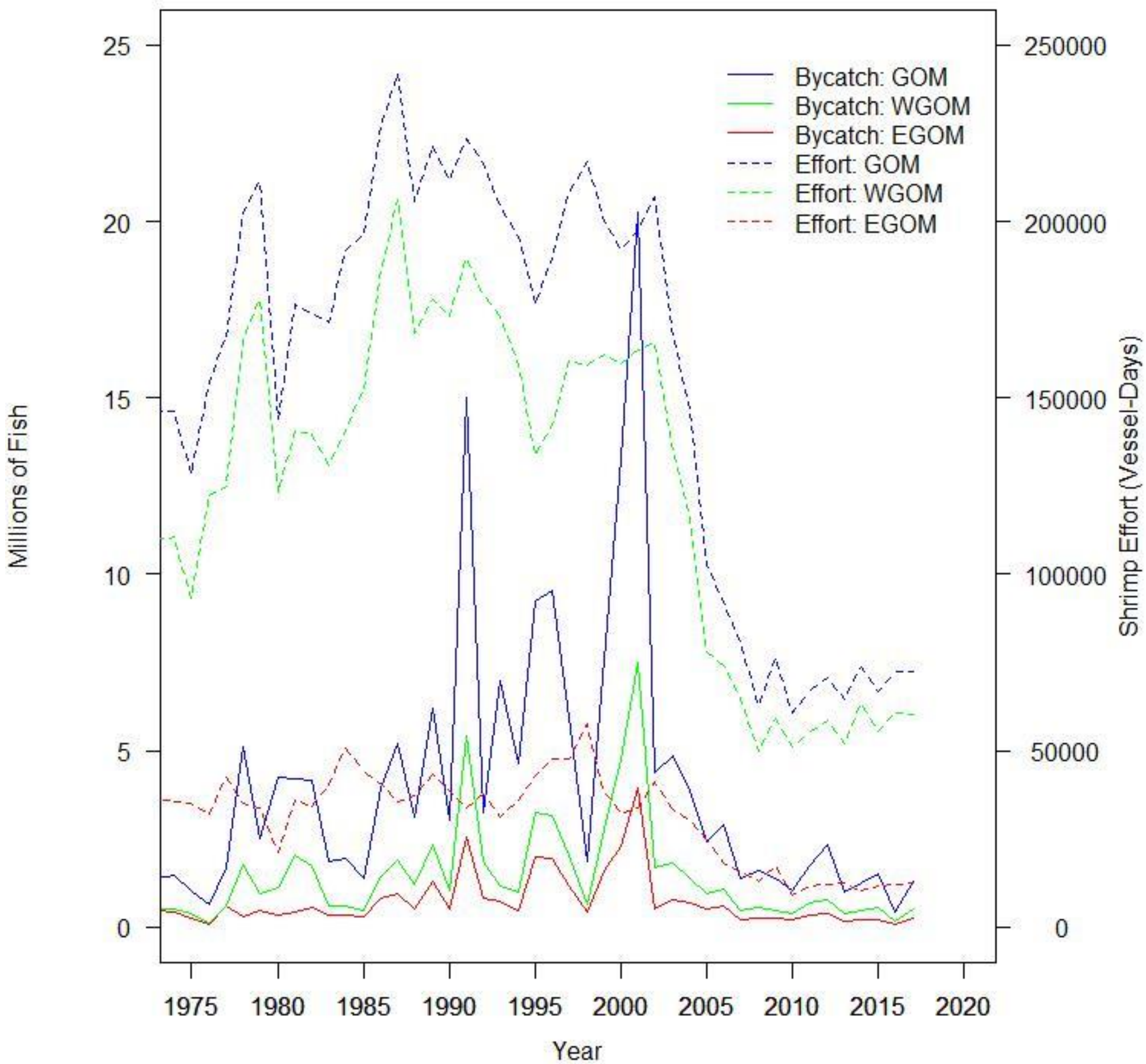

Figure 3. Annual bycatch (median in millions of fish) of grey triggerfish in the Gulf of Mexico shrimp fishery and shrimp fishery effort (vessel-days) provided by the NMFS Galveston Lab (calendar year).

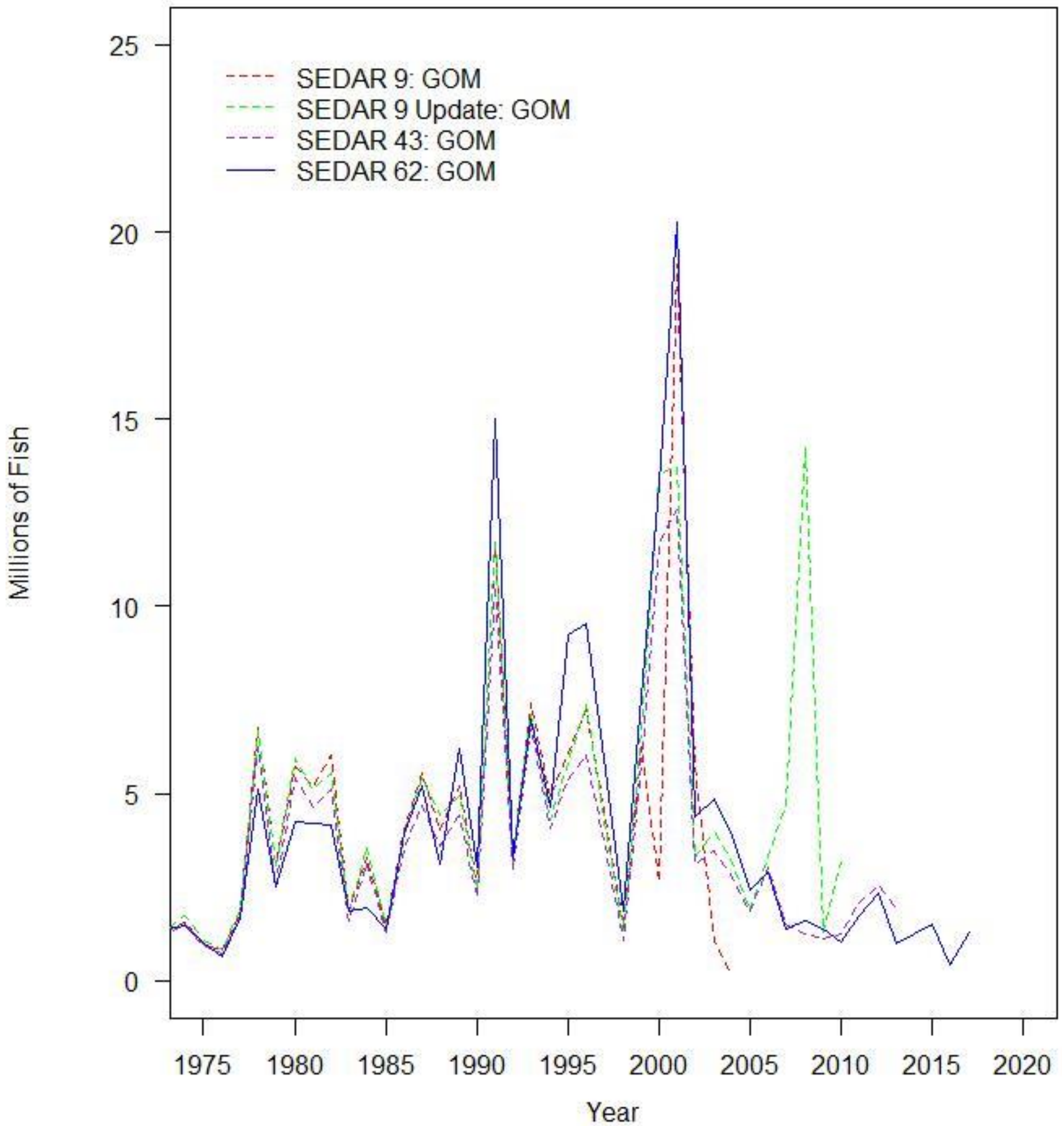

Figure 4. Annual bycatch (median in millions of fish) of grey triggerfish in the Gulf of Mexico shrimp fishery for the SEDAR 62 and previous SEDAR runs (calendar year).

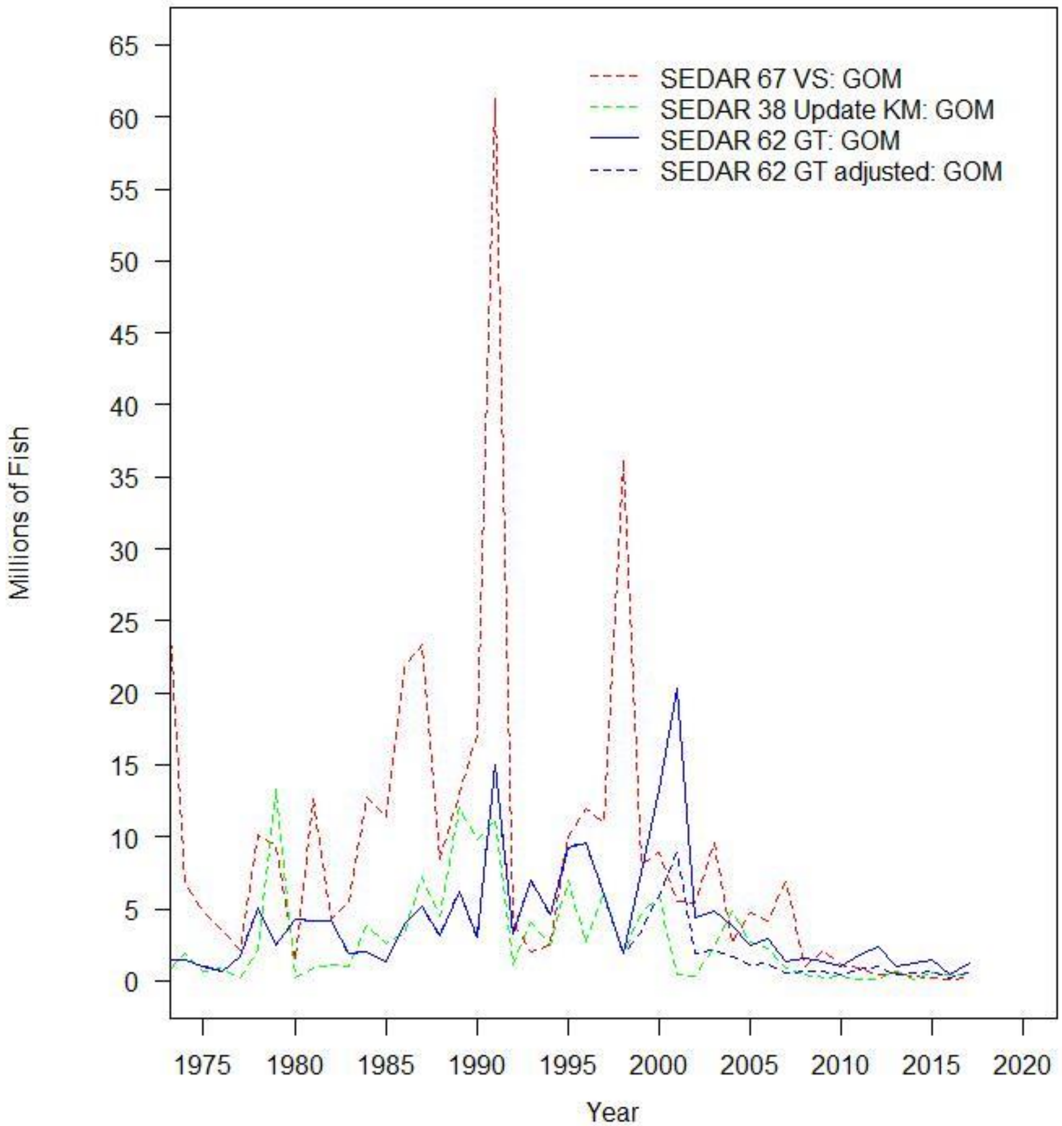

Figure 5. Annual bycatch (median in millions of fish) of grey triggerfish (SEDAR 62), vermilion snapper (SEDAR 67) and king mackerel (SEDAR 38 Update) in the Gulf of Mexico shrimp fishery for 1972-2017 (calendar year). Adjusted SEDAR 62 GT values for 1989-2017 are obtained by multiplying the GOM BRD adjustment factor for grey triggerfish during mandatory BRD requirements (1999-2007) (0.423) by SEDAR 62 GT values for 1989-2017 (see Table 10 for details).

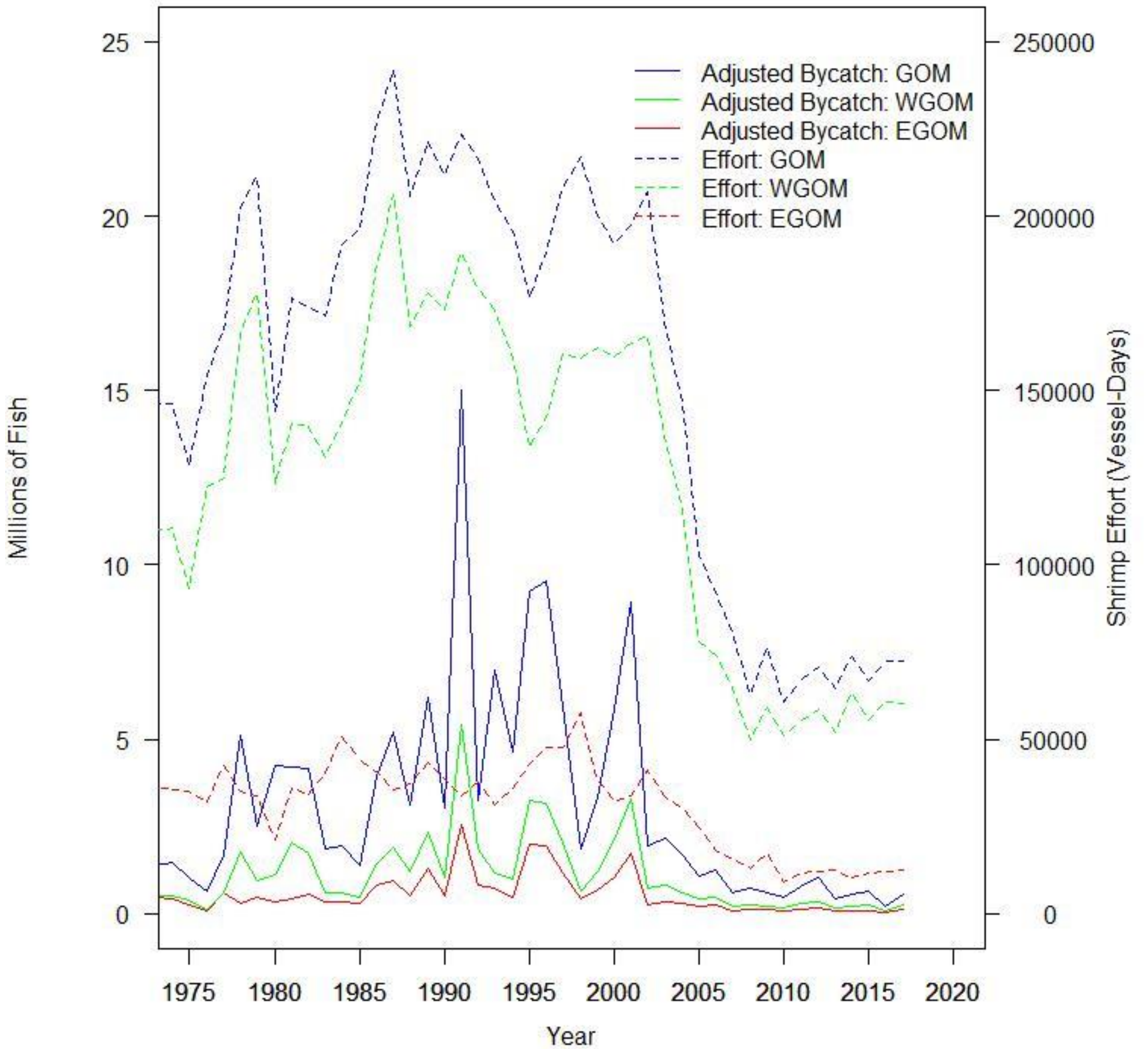

Figure 6. Adjusted annual bycatch (median in millions of fish) of grey triggerfish in the Gulf of Mexico shrimp fishery and shrimp fishery effort (vessel-days) provided by the NMFS Galveston Lab (calendar year). Adjusted SEDAR 62 values for 1989-2017 are obtained by multiplying the GOM BRD adjustment factor for grey triggerfish during mandatory BRD requirements (1999-2007) (0.423) by SEDAR 62 values for 1989-2017 (see table 10 for details).

Appendix. WinBUGS code for the sensitivity run: 3-season, 4-area, 3-depth zone, 2-dataset (without separate use/non-use of BRD data), error-in-effort and error-in-nets-per-vessel models used in SEDAR62.

```
model  GOM GT_3dp_2dset_h35140 1972-2017 (46 years) rsbycatch02 {

#Zhang need to update the endyr, and h_up with new data
#Zhang a lot of more missing CPUE in GT than KM and VS, so h is much smaller
#Zhang season 1=Jan-Apr, season 2=May-Aug, season 3=Sept-Dec
#Zhang NOT included BRD effect (see SEDAR7-DW-54 text and Appendix)
#Zhang report bycatch for EGOM and WGOM, separately
#Zhang as these estimates are numerical (not analytical) solutions with great uncertainties,
#Zhang GOM does not exactly equal sum of EGOM and WGOM
#Zhang especially we will use median instead of mean.

#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 and vermilion snapper,
# however, the shapes of the posteriors for the r's are clearly dominated by the lower bound of the prior
# (Zhang, it is a boundary problem).

r~dunif(0.03,5)                              #Zhang r is the shape parameter of gamma distribution. Be careful with LB
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 GT 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
for (m in 1:2)  {                            #Zhang 2 datasets (not separate BRD):  1=non-BRD&BRD, 2=Research
 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
    for (m in 1:2)  {                        #Zhang 2 datasets, m
     local[i,j,k,l,m]~dnorm(0,tau)           #Zhang local term
     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_2DSET_1972_2017
#Zhang dgamma with 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 1:35140) {                                            #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 NOT included BRD effect, so no-BRD&BRD_CPUE 1 (i.e. y[i,j,k,l,1]) will be used for all years
#Zhang take (i.e. bycatch) for 1972-1997 (i.e. i=1:26), prior mandatory BRD
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&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&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 no-BRD&BRD_CPUE 1 (i.e. y[27,2,k,l,1])
  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,1]*npv[27,2,k,l]*effort[27,2,k,l]
    }
   }
#Zhang season 3, all areas and depths, use no-BRD&BRD_CPUE 1 (i.e. y[27,3,k,l,1])
  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,1]*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 no-BRD&BRD CPUE 1 (i.e. y[i,j,k,l,1])
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,1]*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
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 GT
#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 median of annual medians (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
}
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
```