Shrimp fishery bycatch estimates for Gulf of Mexico king mackerel, 1978-2017

Zhang, X. and J. Isely

2019 SEDAR38-WP-03

29 April 2020

Please cite this document as:

Zhang, X. and J. Isely. 2020. Shrimp fishery bycatch estimates for Gulf of Mexico king mackerel, 1978-2017. 2019-S38Update-WP-03. SEDAR, North Charleston, SC. 23 pp.

Shrimp Fishery Bycatch Estimates for Gulf of Mexico King Mackerel, 1972-2017

Zhang, X. and J. Isely

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

Abstract

Shrimp bycatch estimates for Gulf of Mexico king mackerel 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 king mackerel. 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 fishing years of 1972-2017 range from 0.114-12.370 millions of age-0 king mackerel.

Methods

Shrimp bycatch estimates for Gulf of Mexico king mackerel 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 king mackerel. The recommended prior choices for king mackerel 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 $CPUE_{[i,j,k,l,m]}$ 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. 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 and the Gulf of Mexico fishing year definitions (July 1-June 30).

Results and discussion

Estimates of shrimp fishery bycatch for fishing years of 1972-2017 range from 0.114-12.370 millions of age-0 king mackerel 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 and Figure 3). The statistics of marginal posterior densities of the grand median of annual median estimates (1972-2017) king mackerel 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 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 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	636		10.00%	1.89%		1.200	0.373
1973		81	1137		0.00%	0.09%		0.000	0.011
1974		80	1933		2.50%	0.36%		0.150	0.124
1975		175	1702		1.14%	0.24%		0.504	0.035
1976		315	1631		1.27%	0.00%		0.194	0.000
1977		263	1298		1.52%	0.23%		0.002	0.028
1978		266	1098		3.01%	0.27%		0.078	0.022
1979		1	745		0.00%	0.94%		0.000	0.145
1980		296	1479		0.34%	0.27%		0.001	0.016
1981		192	1546		2.08%	0.13%		0.277	0.012
1982		56	1497		1.79%	0.07%		0.135	0.004
1983			1180			0.00%			0.000
1984			1455			0.55%			0.146
1985			661			0.91%			0.074
1986			434			0.46%			0.028
1987			395			2.03%			0.232
1988			418			2.39%			0.158
1989			420			4.52%			0.611
1990			492			4.27%			0.268
1991			488			3.89%			0.744
1992		636	476		3.14%	1.89%		0.041	0.068
1993	196	1233	500	1.53%	6.81%	6.00%	0.006	0.125	0.361
1994	152	853	477	0.66%	2.70%	4.19%	0.042	0.093	0.705
1995	139	482	435	1.44%	4.98%	5.29%	0.058	0.127	0.747
1996	7	158	464	0.00%	1.27%	3.23%	0.000	0.014	0.167
1997	6	103	434	0.00%	1.94%	4.61%	0.000	0.018	0.158
1998	78	76	387	0.00%	1.32%	4.65%	0.000	0.002	0.292
1999			509			4.13%			0.194
2000			491			5.30%			0.260
2001	676	483	356	0.74%	0.62%	6.74%	0.022	0.012	0.331
2002	2006	1605	469	1.00%	1.12%	3.62%	0.022	0.025	0.220
2003	799	809	422	1.88%	2.22%	7.82%	0.050	0.050	0.570
2004	1099	1074	413	6.92%	7.36%	9.69%	0.299	0.258	0.985
2005	525	514	233	5.71%	5.25%	4.72%	0.281	0.274	0.241
2006	32		385	0.00%		8.05%	0.000		0.482
2007	1504		422	4.85%		12.56%	0.070		1.203
2008	3415	41	553	4.39%	0.00%	3.07%	0.095	0.000	0.272
2009	3190	55	622	2.38%	0.00%	4.66%	0.039	0.000	0.314
2010	2632	25	411	1.71%	0.00%	6.81%	0.037	0.000	0.833
2011	2996	143	331	1.97%	0.70%	2.11%	0.027	0.005	0.084
2012	3183	53	369	3.61%	0.00%	2.44%	0.046	0.000	0.636
2013	3852	9	222	4.78%	11.11%	7.21%	0.167	0.059	0.699
2014	4447	31	380	1.17%	9.68%	2.63%	0.014	0.122	0.084
2015	3570		382	2.72%		5.50%	0.070		0.344
2016	4738	37	405	2.47%	0.00%	1.98%	0.066	0.000	0.059
2017	5510		385	2.07%		0.26%	0.053		0.005
Totals or Averages	44752	10155	31578	2.76%	3.28%	2.13%	0.068	0.107	0.197

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 4A. 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 4B. 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 (fishing year). January 1-June 30 portion 2018 of 2017 fishing year estimates are not complete but use an average for the last three years for the missing months.

Fishing Year	Effort	SE
1972	147457	410
1973	155937	547
1974	130637	348
1975	142237	423
1976	151578	483
1977	174612	646
1978	213986	1339
1979	166264	1359
1980	169298	763
1981	176964	388
1982	174622	481
1983	175644	582
1984	204151	563
1985	210873	527
1986	230724	684
1987	220998	734
1988	219223	734
1989	209582	785
1990	220563	788
1991	218856	777
1992	216338	790
1993	201041	930
1994	191005	760
1995	176651	591
1996	197528	698
1997	212654	774
1998	216853	798
1999	190961	738
2000	191724	727
2001	199393	856
2002	190958	899
2003	162592	591
2004	132616	459
2005	98736	317
2006	82684	257
2007	73748	421
2008	70667	391
2009	70606	180
2010	62728	168
2011	66532	175
2012	69021	211
2013	67896	231
2014	69668	267
2015	71631	221
2016	75844	235
2017	68893	199

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

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)

Table 7A. Statistics of marginal posterior densities of annual estimates king mackerel as bycatch (millions of fish) in the Gulf of Mexico shrimp fishery (calendar year).

Year	Mean	SD	MC error	2.50%	Median	97.50%
1972	41.010	131.300	2.481	1.729	15.570	217.500
1973	1.298	6.295	0.104	0.075	0.526	6.238
1974	3.655	8.240	0.176	0.399	1.890	17.090
1975	1.619	6.276	0.105	0.141	0.684	7.609
1976	1.589	3.930	0.066	0.235	0.867	7.156
1977	0.447	1.195	0.021	0.036	0.195	2.389
1978	4.404	16.780	0.263	0.565	2.153	17.970
1979	35.970	99.630	1.940	1.489	13.320	198.300
1980	0.347	1.244	0.019	0.033	0.170	1.600
1981	2.158	7.387	0.122	0.194	0.882	12.070
1982	2.890	10.890	0.206	0.183	1.095	15.320
1983	2.590	10.340	0.170	0.109	1.004	14.150
1984	10.500	52.330	0.812	0.533	3.880	52.410
1985	6.483	19.970	0.304	0.299	2.533	35.110
1986	9.041	35.440	0.501	0.405	3.302	48.290
1987	18.640	62.970	0.947	0.891	7.214	103.000
1988	11.570	34.300	0.497	0.520	4.539	62.580
1989	30.150	91.130	1.397	1.433	12.020	164.500
1990	26.170	78.410	1.378	1.320	9.847	141.100
1991	28.570	108.800	1.464	1.443	11.200	147.500
1992	1.808	4.452	0.059	0.444	1.136	6.580
1993	6.443	10.040	0.167	1.643	4.073	25.870
1994	4.419	9.673	0.159	0.860	2.508	19.110
1995	12.530	28.040	0.423	1.978	6.981	56.150
1996	6.925	25.180	0.355	0.350	2.665	36.130
1997	14.940	40.860	0.619	0.960	6.097	81.470
1998	4.308	9.803	0.149	0.286	1.928	22.950
1999	11.110	29.700	0.525	0.645	4.722	57.710
2000	15.000	60.900	0.984	0.747	5.816	77.710
2001	0.707	1.370	0.023	0.140	0.393	3.233
2002	0.515	0.741	0.012	0.173	0.378	1.653
2003	3.767	6.776	0.099	0.677	2.315	15.200
2004	6.494	8.226	0.116	2.387	4.861	19.800
2005	3.890	12.350	0.169	1.143	2.647	12.370
2006	5.547	29.300	0.400	0.307	2.201	27.550
2007	1.421	2.878	0.058	0.415	0.938	4.911
2008	0.481	0.258	0.004	0.306	0.442	0.860
2009	0.284	0.115	0.002	0.147	0.259	0.575
2010	0.577	1.304	0.017	0.186	0.374	2.084
2011	0.169	0.093	0.002	0.101	0.153	0.337
2012	0.119	0.037	0.001	0.077	0.113	0.192
2013	0.728	0.151	0.003	0.519	0.706	1.042
2014	0.060	0.011	0.000	0.043	0.059	0.085
2015	0.557	0.270	0.004	0.310	0.505	1.083
2016	0.510	0.195	0.003	0.297	0.471	0.944
2017	0.435	0.190	0.003	0.242	0.391	0.869

Table 7B. Statistics of marginal posterior densities of annual estimates king mackerel as bycatch (millions of fish) in the Gulf of Mexico shrimp fishery (fishing year). January 1-June 30 portion 2018 of 2017 fishing year estimates are not complete but use an average for the last three years for the missing months.

Fishing Year	Mean	SD	MC error	2.50%	Median	97.50%
1972	27.130	97.390	1.730	1.045	9.173	161.200
1973	2.389	7.921	0.139	0.278	1.228	10.590
1974	2.778	6.263	0.117	0.349	1.449	13.220
1975	1.157	4.560	0.076	0.111	0.477	5.275
1976	1.565	3.110	0.050	0.254	0.895	7.029
1977	0.983	2.304	0.035	0.162	0.567	4.261
1978	14.090	37.470	0.635	1.325	6.389	66.270
1979	25.770	81.650	1.468	0.912	8.325	153.700
1980	0.499	1.061	0.015	0.109	0.323	1.800
1981	2.430	7.943	0.124	0.260	1.076	12.490
1982	2.956	9.926	0.174	0.229	1.213	15.070
1983	4.189	11.310	0.183	0.355	1.998	20.010
1984	10.090	51.360	0.736	0.673	4.078	47.670
1985	7.168	19.410	0.292	0.572	3.269	35.030
1986	12.480	41.350	0.567	0.917	5.552	64.250
1987	15.940	45.990	0.684	1.109	6.705	83.610
1988	17.330	42.640	0.593	1.445	8.443	81.480
1989	27.800	82.360	1.262	1.945	12.290	143.000
1990	28.380	78.270	1.210	2.142	12.370	148.300
1991	20.210	70.410	0.978	1.035	7.325	109.200
1992	1.575	4.120	0.053	0.511	1.064	4.986
1993	7.476	10.490	0.169	2.164	5.060	27.640
1994	7.679	14.130	0.228	1.582	4.623	33.480
1995	9.662	25.030	0.365	1.529	5.169	43.730
1996	8.833	24.850	0.360	0.859	4.217	41.810
1997	13.010	39.140	0.555	0.944	5.260	71.100
1998	6.297	13.730	0.219	0.576	3.132	30.320
1999	12.000	36.670	0.588	1.021	5.561	58.250
2000	10.730	41.590	0.647	0.589	3.863	58.130
2001	0.563	1.007	0.016	0.141	0.328	2.442
2002	0.614	0.857	0.014	0.185	0.429	2.075
2003	5.578	7.115	0.107	1.950	4.129	17.690
2004	5.710	13.300	0.173	2.072	4.028	17.570
2005	4.195	7.784	0.114	0.988	2.688	16.260
2006	4.692	28.550	0.391	0.457	1.943	22.330
2007	0.920	1.659	0.030	0.421	0.694	2.341
2008	0.287	0.091	0.001	0.203	0.274	0.431
2009	0.313	0.115	0.002	0.173	0.289	0.610
2010	0.605	1.305	0.017	0.211	0.400	2.143
2011	0.123	0.051	0.001	0.081	0.114	0.218
2012	0.324	0.070	0.001	0.235	0.313	0.469
2013	0.502	0.097	0.002	0.362	0.489	0.713
2014	0.251	0.097	0.002	0.144	0.234	0.457
2015	0.605	0.245	0.004	0.394	0.561	1.057
2016	0.399	0.115	0.002	0.254	0.377	0.670
2017	0.492	0.167	0.003	0.323	0.460	0.838

Table 8. Statistics of marginal posterior densities of the grand median of annual median estimates (1972-2017) king mackerel as bycatch (millions of fish) in the Gulf of Mexico shrimp fishery.

Year Defination	Mean	SD	MC error	2.50%	Median	97.50%
Calender Year	1.530	0.435	0.016	0.867	1.465	2.538
Fishing Year	1.884	0.576	0.022	1.008	1.806	3.244

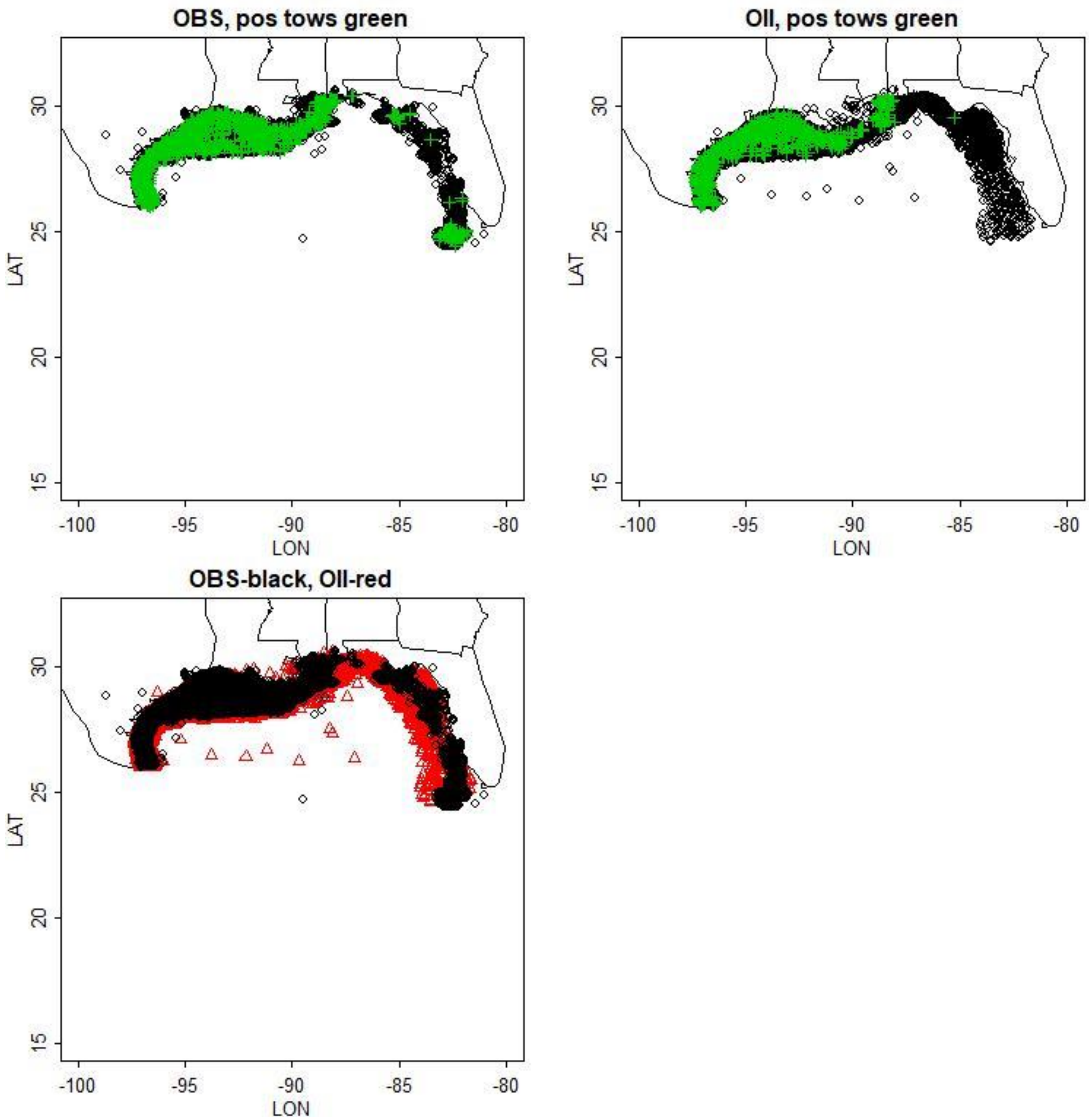

Figure 1. Spatial plots of shrimp observer data and Oregon II of SEAMAP data with positive tows shown in green and overlap of Oregon II of SEAMAP (red) and Observer (black).

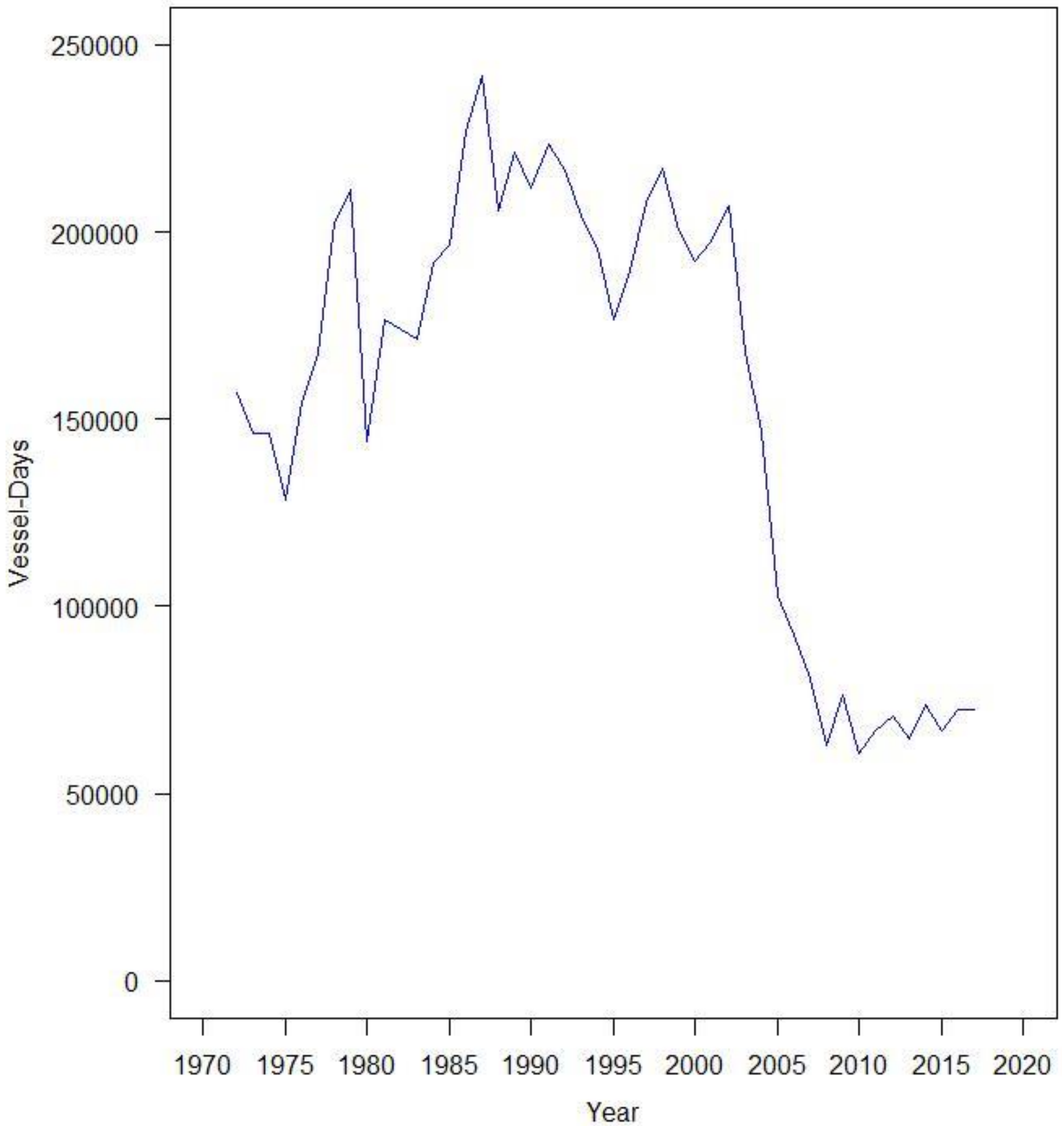

Figure 2A. Gulf of Mexico shrimp fishery effort (vessel-days) provided by the NMFS Galveston Lab (calendar year).

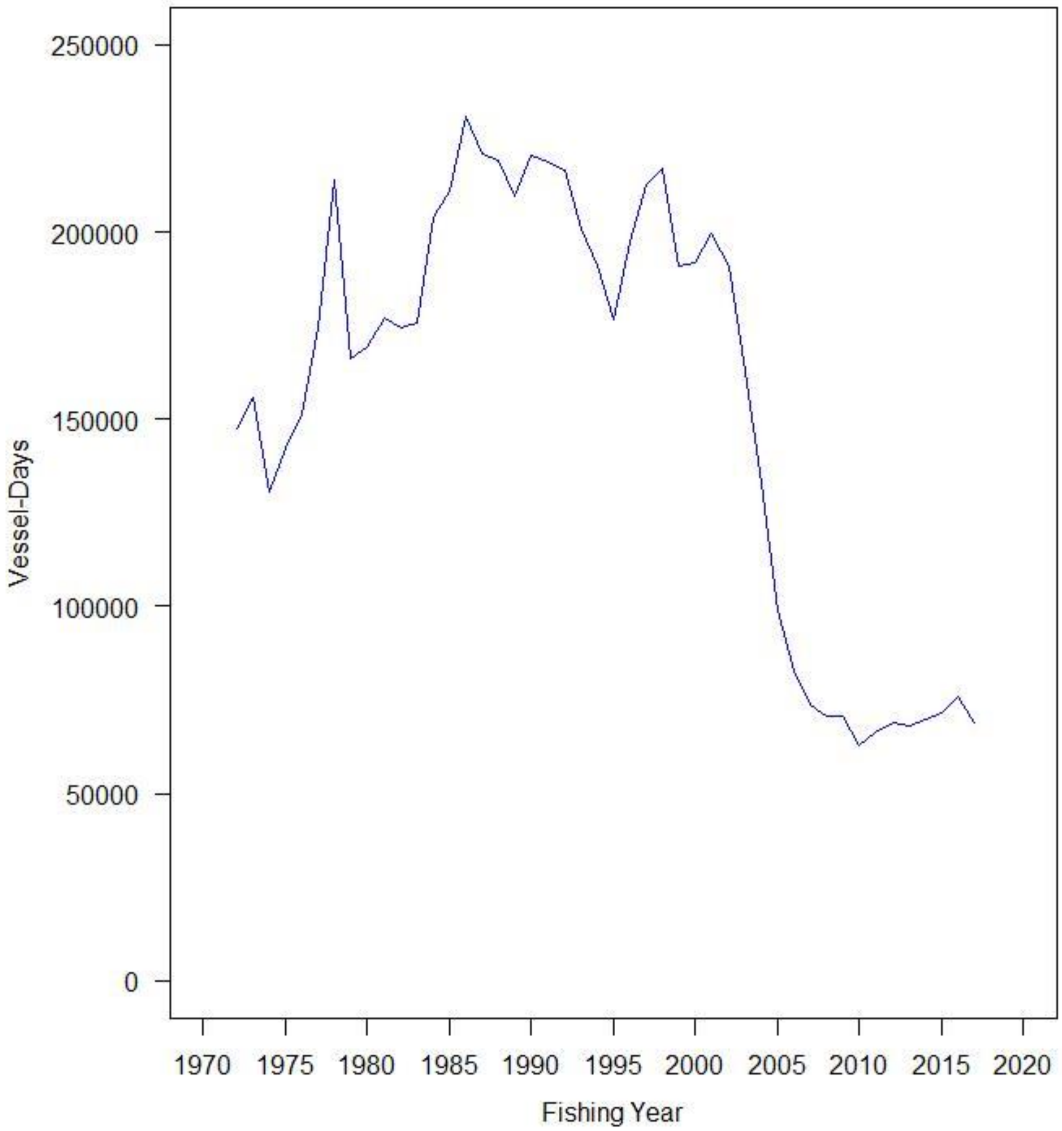

Figure 2B. Gulf of Mexico shrimp fishery effort (vessel-days) provided by the NMFS Galveston Lab (fishing year). January 1-June 30 portion 2018 of 2017 fishing year estimates are not complete but use an average for the last three years for the missing months.

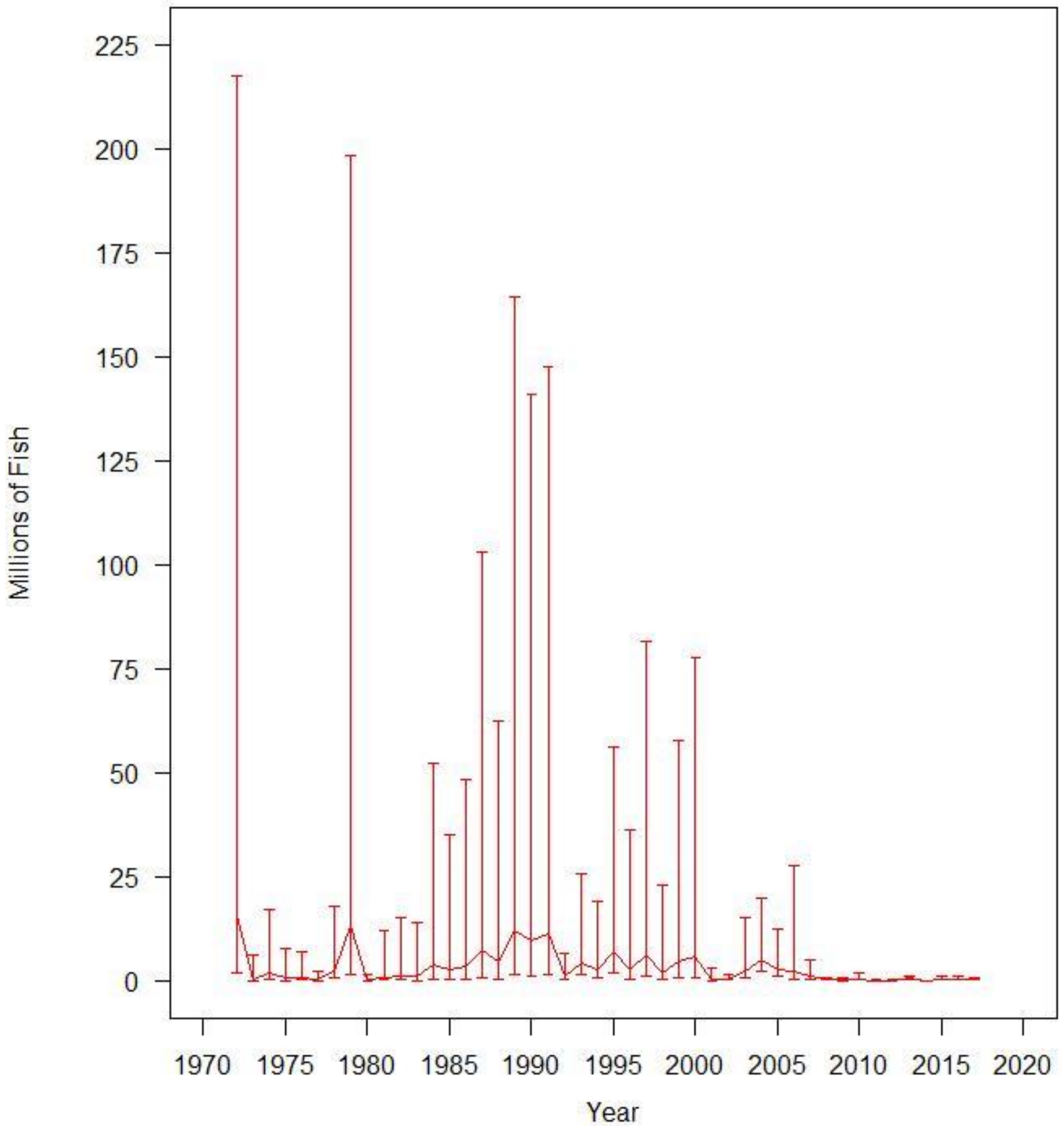

Figure 3A. Median annual bycatch (95% CI) for king mackerel in the Gulf of Mexico shrimp fishery (calendar year).

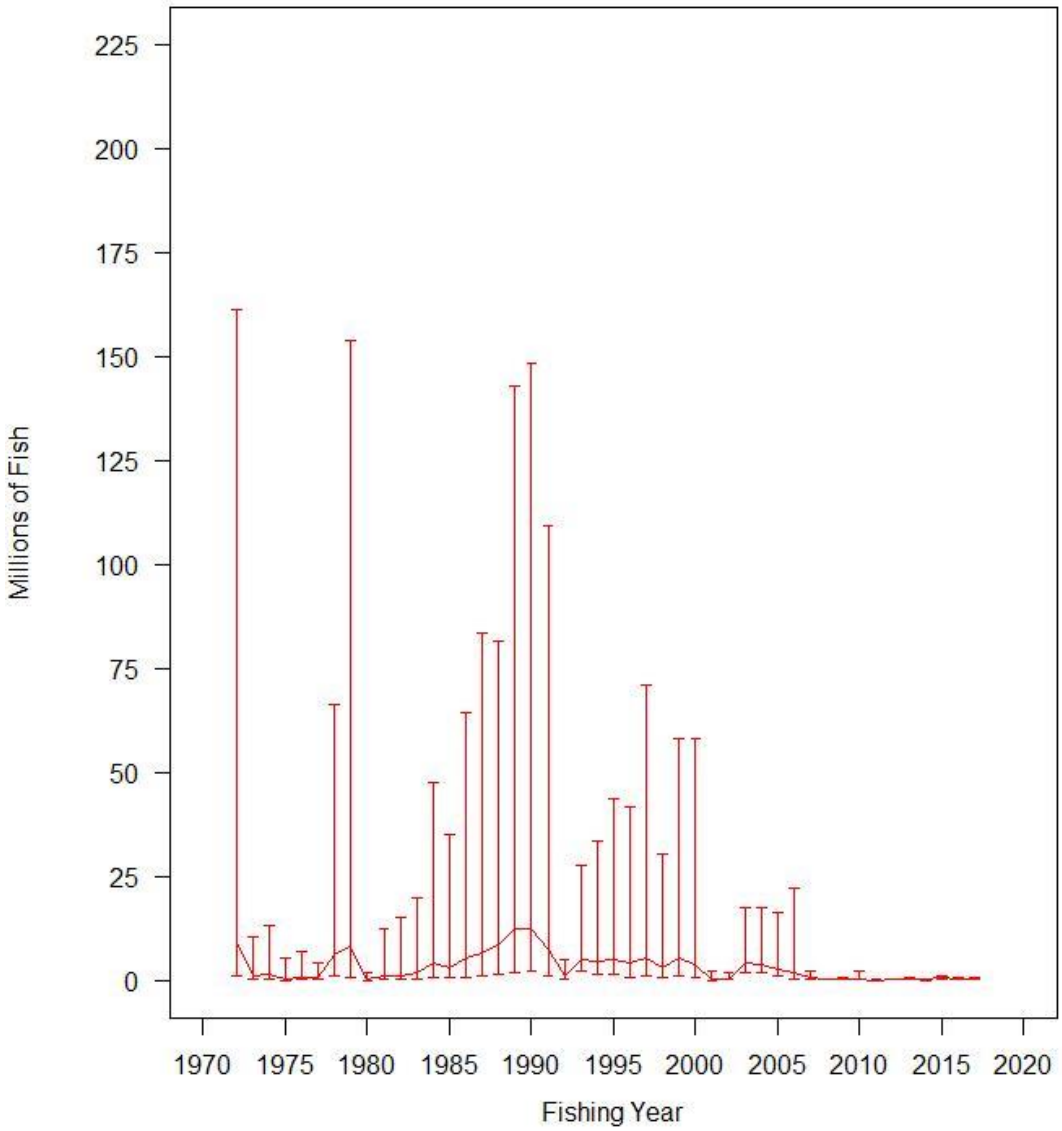

Figure 3B. Median annual bycatch (95% CI) for king mackerel in the Gulf of Mexico shrimp fishery (fishing year). January 1-June 30 portion 2018 of 2017 fishing year estimates are not complete but use an average for the last three years for the missing months.

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 model used in this paper.

```
model  GOM KM_3dp_3dset_h86730 1972-2017 (46 years) rsbycatch02 {

#Zhang need to update the endyr, and h_up with new data
#Zhang do both calendar year (annual) and fishing year (fishannual GOM KM 7/1-6/30)
#Zhang season 1=Jan-Apr, season 2=May-Aug, season 3=Sept-Dec
#Zhang fishing year = current year (half seson2 + season3) and next year (season 1 + half season 2)
#Zhang included BRD effect (see SEDAR7-DW-54 text and Appendix)

r~dunif(0.03,5)                       #Zhang r is the shape parameter of gammma 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 fyears, 1972-2017
  yx[i]~dnorm(-1,0.7)                 #Zhang KM 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)         #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. KMBYCATCH_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 1:86730) {                  #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
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
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
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 Convert from calendar year to GOM KM fishing year (July1 to June 30)
#Zhang for the first year to end year -1 fishing year (1:45) (1972-2016)
#Zhang fishing year =current year (half seson2 and season3) + next year (season1 and half season2)
for (i in 1:45) {                                                 #Zhang need to update the end year -1
        fishannual[i]<-trimester[i,2]/2+trimester[i,3]+trimester[i+1,1]+trimester[i+1,2]/2
}

#Zhang for the last fishing year i.e. 46 (2017)
#Zhang fishing year 46=year 46 (half seson2 and season3) + missing year 47 (season1 and half season2)
#Zhang missing lyear 47 (season1 and half season2) = the last 3 yrs (46,45,44) season1 & half season 2 averages
fishannual[46]<-trimester[46,2]/2+trimester[46,3]+(trimester[46,1] + trimester[45,1]+trimester[44,1])/3 + (trimester[46,2]/2 +
trimester[45,2]/2+trimester[44,2]/2)/3

#Zhang East and West do three seasons
for (i in 1:46) {                                                                  #Zhang need to update the end year
  for (j in 1:3)    {
    trimesterE[i,j]<-sum(take[i,j,1:2,])                                           #Zhang season specific East of GOM annual
    trimesterW[i,j]<-sum(take[i,j,3:4,])                                           #Zhang season specific West of GOM annual
  }
}

#Zhang East and West for the first year to end year -1 fishing year (1:45) (1972-2016)
for (i in 1:45) {                                                                  #Zhang need to update the end year -1
        fishannualE[i] <-trimesterE[i,2]/2 +trimesterE[i,3] +trimesterE[i+1,1] +trimesterE[i+1,2]/2
        fishannualW[i]<-trimesterW[i,2]/2+trimesterW[i,3]+trimesterW[i+1,1]+trimesterW[i+1,2]/2
}

#Zhang East and West for the last fishing year i.e. 46 (2017)
#Zhang fishing year 46=year 46 (half seson2 and season3) + missing year 47 (season1 and half season2)
#Zhang missing lyear 47 (season1 and half season2) = the last 3 yrs (46,45,44) season1 & half season 2 averages
fishannualE[46] <-trimesterE[46,2]/2+trimesterE[46,3]+  (trimesterE[46,1] +  trimesterE[45,1]+ trimesterE[44,1])/3+
(trimesterE[46,2]/2 +  trimesterE[45,2]/2+ trimesterE[44,2]/2)/3
fishannualW[46]<-trimesterW[40,2]/2+trimesterW[40,3]+(trimesterW[40,1]+ trimesterW[39,1]+trimesterW[38,1])/3+
(trimesterW[46,2]/2 + trimesterW[45,2]/2+trimesterW[44,2]/2)/3

#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 Gulfwise, East, West median of fishannual medium (i.e. mofam), 46, so use average 23 and 24
fishmofam<-    (ranked(fishannual[1:46],23) + ranked(fishannual[1:46],24))/2
fishmofamE<-  (ranked(fishannualE[1:46],23) + ranked(fishannualE[1:46],24))/2
fishmofamW<- (ranked(fishannualW[1:46],23) + ranked(fishannualW[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
```