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2019 SEDAR28-WP-07

23 June 2020

Please cite this document as:

Zhang, X. 2020. Shrimp Fishery Bycatch Estimates for Gulf of Mexico Cobia, 1972-2017. 2019-S28Update-WP-07. SEDAR, North Charleston, SC. 34 pp.

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2/21/2020

Summary

A WinBUGS Bayesian approach was developed by Nichols (2004a) and used for the SEDAR 7 Gulf of Mexico (GOM) red snapper shrimp bycatch estimates in SEDAR7-DW-3. This model was then modified to incorporate estimates of uncertainty for shrimping effort, include variable "nets per vessel" estimates, and separate observer data into BRD (i.e. Bycatch Reduction Device) 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 data-rich species - red snapper, and data-limited species - 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 data-rich species - red snapper, estimates with BRDs could not be produced for data-limited species - grey triggerfish, amberjack, and vermilion snapper in SEDAR 9 (Nichols 2006). Now that there are more shrimp observer data and more overlapping years in the use/non-use of BRDs for GOM king mackerel and vermilion snapper than were available for SEDAR 9, we have been able to model effects of BRDs (i.e. *separating use/non-use of BRD data*) in the recent SEDAR38 Update for GOM king mackerel (Zhang and Isely 2019) and SEDAR67 for GOM vermilion snapper (Zhang and Isely 2020). However, there is remains insufficient additional data related to BRDs for some species. For example, grey triggerfish was not on the list of 22 species for which data were recorded during "Evaluation Protocol" observer trips, instead it was placed in the other grouped finfish category (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 retained Nichols' (2006) conclusion that "It is not possible to obtain an estimate for bycatch with BRDs for triggerfish with the Bayesian model". In the recent SEDAR62 for GOM grey triggerfish 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 (Zhang 2020). Instead, 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 (Zhang 2020). Now that there are more shrimp observer data and more overlapping years in the use/non-use of BRDs for GOM cobia than were available for SEDAR 9, shrimp bycatch estimates for the Gulf of Mexico cobia were generated using the same WinBUGS Bayesian approach developed and modified for red snapper by Nichols (2004a, 2004b, 2006) with *both not separating use/non-use of BRD data run and separating use/non-use of BRD data run, respectively.* For *not separating use/non-use of BRD data run,* estimates of shrimp fishery bycatch (median) for 1972-2017 ranged from 0.001-0.219, 0.001-0.106, and 0.002-0.494 million cobia in the eastern Gulf of Mexico, western Gulf of Mexico, and entire Gulf of Mexico, respectively. For *separating use/non-use of BRD data run,* estimates of shrimp fishery bycatch (median) for 1972-2017 ranged from 0.001-0.446, 0.001-0.239, and 0.002-1.087 million cobia in the eastern Gulf of Mexico, western Gulf of Mexico, and entire Gulf of Mexico, respectively. Estimates of shrimp fishery bycatch (median) from *both not separating use/non-use of BRD data run and separating use/non-use of BRD data run* were very low and very similar for the most recent 12 years (2006-2017).

Methods

A WinBUGS Bayesian approach was developed by Nichols (2004a) and used for the SEDAR 7 Gulf of Mexico red snapper shrimp bycatch estimates in SEDAR7-DW-3. This model was then modified to incorporate estimates of uncertainty for shrimping effort, include variable "nets per vessel" estimates, and separate 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 data-rich species (red snapper) and data-limited species (vermilion snapper, grey triggerfish, great amberjack, and king mackerel) in SEDAR9-AW-3 (Nichols 2006). The same prior value (i.e. -1) for the year effects for data-limited species (vermilion snapper, grey triggerfish, great amberjack, and king mackerel) in SEDAR9-AW-3 (Nichols 2006) was used for cobia.

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. 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 most of overlapped years prior 2006 (Table 2). However, the CPUE from commercial vessels with non-BRD was similar to the CPUE from commercial vessels with BRD for the overlapped years during the most recent 12 years (2006-2017) (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 fathom 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). The ratios/relationships between SEAMAP CPUEs and observer program CPUEs for the overlapping years were used to fill spatio-temporal data gaps in shrimp observer coverage within the WinBUGS Bayesian bycatch model (i.e. only "borrowed" trends, not absolute values from SEAMAP CPUE).

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 2012a and 2012b) (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 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 (-1) for data-limited species - vermilion snapper, grey triggerfish, great amberjack, and king mackerel in SEDAR 9 (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-limited 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. The data-limited species, cobia, the shape of the posterior for the r values of the conjugate gamma-Poisson distribution tended to be near 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 data-rich species - red snapper, estimates with BRDs could not be produced for data-limited species - grey triggerfish, amberjack, and vermilion snapper in SEDAR 9 (Nichols 2006). Since there are more shrimp observer data and more overlapping years in the use/non-use of BRDs for GOM king mackerel and vermilion snapper than were available for SEDAR 9, we have been able to model effects of BRDs (i.e. separating use/non-use of BRD data) in the recent SEDAR38 Update for GOM king mackerel (Zhang and Isely 2019) and SEDAR67 for GOM vermilion snapper (Zhang and Isely 2020). However, there is remains insufficient additional data related to BRDs for some species. For example, grey triggerfish was not on the list of 22 species for which data were recorded during "Evaluation Protocol" observer trips, instead it was placed in the other grouped finfish category (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 retained Nichols' (2006) conclusion that "It is not possible to obtain an estimate for bycatch with BRDs for triggerfish with the Bayesian model". In the recent SEDAR62 for GOM grey triggerfish 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 (Zhang 2020). Instead, 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 (Zhang 2020). *Now that there are more shrimp observer data and more overlapping years in the use/non-use of BRDs for GOM cobia than were available for SEDAR 9*, shrimp bycatch estimates for the Gulf of Mexico cobia were generated using the same WinBUGS Bayesian approach developed and modified for red snapper by Nichols (2004a, 2004b, 2006) with *both not separating use/non-use of BRD data run and separating use/non-use of BRD data run, respectively* (see Appendix A and Appendix B 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

For *not separating use/non-use of BRD data run*, estimates of shrimp fishery bycatch (median) for 1972-2017 ranged from 0.001-0.219, 0.001-0.106, and 0.002-0.494 million cobia in the eastern Gulf of Mexico, western Gulf of Mexico, and entire Gulf of Mexico, respectively (Table 7, Figure 3A). For *separating use/non-use of BRD data run*, estimates of shrimp fishery bycatch (median) for 1972-2017 ranged from 0.001-0.446, 0.001-0.239, and 0.002-1.087 million cobia in the eastern Gulf of Mexico, western Gulf of Mexico, and entire Gulf of Mexico, respectively (Table 8, Figure 3B). The estimates of shrimp bycatch have very large confidence intervals in most years (Tables 7 and 8). The statistics of marginal posterior densities of the grand median estimates of annual median estimates (1972-2017) of cobia bycatch (millions of fish) in the Gulf of Mexico shrimp fishery are reported in Table 9. Estimates of shrimp fishery bycatch from the SEDAR 28 Update with *not separating use/non-use of BRD data run* were similar to the previous SEDAR 28 (*note: only did not separating use/non-use of BRD data run*) for the overlapping years (Table 10 and Figure 4). Estimates of shrimp fishery bycatch (median) from *not separating use/non-use of BRD data run* were much lower than *separating use/non-use of BRD data run* prior to 1998 (i.e. non-mandatory BRD requirements period) (Tables 7 and 8, Figure 4). However, estimates of shrimp fishery bycatch (median) from *both not separating use/non-use of BRD data run and separating use/non-use of BRD data run* were very similar for the most recent 12 years (2006-2017) (Tables 7 and 8, Figure 4). 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 the recent SEDAR 38 update for GOM king mackerel (Zhang and Isely 2019), SEDAR 68 for GOM vermilion snapper (Zhang and Isely 2020), and this SEDAR 28 Update for GOM cobia.

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. As I mentioned earlier that although Nichols was able to use this model to evaluate the impact of BRDs for data-rich species - red snapper, estimates with BRDs could not be produced for data-limited species - grey triggerfish, amberjack, and vermilion snapper in SEDAR 9 (Nichols 2006). It would be desirable to use this model to evaluate the impact of BRDs when sufficient number of observer data and overlapping years in the use/non-use of BRD data are available. However, evaluating the impact of BRDs based on very limited number of observer data and overlapping years in the use/non-use of BRD data sometimes may produce nonsensical results. Now that there are more shrimp observer data and more overlapping years in the use/non-use of BRDs for some species than were available for SEDAR 9. When it is practical, both not separating use/non-use of BRD data run and separating use/non-use of BRD data run should be carried out. If the main objective is to be "consistent" with previous SEDARs, then estimates from not separating use/non-use of BRD data run should been recommended. If the main objective is to be more "accurate", then estimates from separating use/non-use of BRD data run should be preferred. Regardless, both estimates should be tested in the stock assessment model so that the sensitivity of the stock status to the shrimp bycatch estimates can be evaluated.

The WinBUGS Bayesian approach was developed and modified by Nichols (2004a, 2004b, 2006) 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 by modeling the data from the poor-quality period and good-quality period (e.g. mandatory observer program) separately. After going thorough peer and/or SEDAR reviews, the estimates from the poor-quality period could been kept as fixed and "grandfathered in" for the future assessments. In this way, we could be more cost effectively to focus on the estimates from the good-quality period (e.g. mandatory observer program), which should be more influential to the stock status. We should comprehensively evaluate the impacts of BRDs and SEAMAP data on the estimated shrimp bycatch for data-rich species (e.g. red snapper), data-limited species that were selected and recorded at the species level (e.g. king mackerel, vermilion snapper, and cobia), and data-limited species that were selected and recorded at the grouped finfish category (e.g. grey triggerfish). We should build a team to work out from end-to-end shrimp bycatch estimates at least one example from each of these 3 groups. After the evaluation results and recommendations going thorough peer and/or SEDAR reviews, we should develop a manual and provide guidance for future shrimp bycatch estimates. Ultimately, our longer term goal is to collect more good quality data from the observer program for generating better shrimp bycatch estimates.

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 Adyan Rios for her support for this project.

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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	no-BRD	SEAMAP-GOM	BRD	no-BRD	SEAMAP-GOM	BRD	no-BRD	SEAMAP-GOM
1972		10	636		0.00%	0.63%		0.000	0.074
1973		81	1137		0.00%	0.09%		0.000	0.016
1974		80	1933		0.00%	0.78%		0.000	0.099
1975		175	1702		1.14%	0.71%		0.017	0.095
1976		315	1631		0.95%	0.55%		0.021	0.033
1977		263	1298		1.14%	0.15%		0.004	0.009
1978		266	1098		0.75%	0.64%		0.001	0.044
1979		1	745		0.00%	1.34%		0.000	0.081
1980		296	1479		0.68%	0.81%		0.092	0.081
1981		192	1546		0.00%	0.39%		0.000	0.023
1982		56	1497		0.00%	0.73%		0.000	0.050
1983			1180			1.27%			0.081
1984			1455			0.62%			0.037
1985			661			0.61%			0.042
1986			434			0.23%			0.009
1987			395			0.51%			0.011
1988			418			0.00%			0.000
1989			420			0.95%			0.016
1990			492			0.81%			0.021
1991			488			1.23%			0.043
1992		635	476		0.79%	1.05%		0.030	0.039
1993	196	1234	500	0.00%	0.41%	3.60%	0.000	0.003	0.138
1994	153	854	477	2.61%	3.16%	2.52%	0.020	0.022	0.041
1995	139	482	435	0.00%	0.62%	2.30%	0.000	0.008	0.040
1996	7	158	464	0.00%	1.27%	2.16%	0.000	0.037	0.055
1997	6	103	434	0.00%	0.00%	2.76%	0.000	0.000	0.122
1998	78	76	387	0.00%	1.32%	1.03%	0.000	0.004	0.033
1999			509			3.14%			0.076
2000			491			0.41%			0.006
2001	676	484	356	0.44%	1.03%	3.37%	0.005	0.022	0.084
2002	2005	1605	469	1.30%	1.00%	1.28%	0.093	0.007	0.034
2003	800	810	422	0.63%	0.99%	1.42%	0.006	0.011	0.043
2004	1101	1076	413	0.18%	0.65%	2.91%	0.001	0.002	0.057
2005	528	518	233	0.38%	1.54%	1.72%	0.005	0.002	0.069
2006	32		385	0.00%		2.08%	0.000		0.045
2007	1507		422	0.93%		1.18%	0.007		0.026
2008	3416	41	553	0.59%	0.00%	1.27%	0.003	0.000	0.081
2009	3192	55	622	0.47%	0.00%	0.64%	0.003	0.000	0.022
2010	2631	25	411	0.46%	0.00%	1.95%	0.001	0.000	0.063
2011	2996	143	331	1.03%	1.40%	0.91%	0.009	0.009	0.024
2012	3188	53	369	0.38%	0.00%	0.81%	0.002	0.000	0.016
2013	3860	9	222	0.21%	0.00%	0.00%	0.002	0.000	0.000
2014	4448	32	380	0.13%	0.00%	0.26%	0.001	0.000	0.032
2015	3575		382	0.11%		0.79%	0.000		0.021
2016	4745	37	405	0.13%	0.00%	0.49%	0.001	0.000	0.010
2017	5511		385	0.20%		0.78%	0.002		0.015
Totals or Averages	44790	10165	31578	0.40%	0.99%	0.98%	0.007	0.012	0.050

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 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).

	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 4B. Gulf of Mexico shrimp fishery effort (vessel-days) and standard error for depth 1 only (<=10 fathoms). 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	9111	49	51396	291	60507	295
1973	9401	60	52171	401	61572	406
1974	9764	59	53783	356	63546	361
1975	9429	48	39353	236	48783	241
1976	8216	56	59593	454	67809	458
1977	12843	83	71348	573	84191	579
1978	13185	100	104025	1019	117210	1024
1979	11103	70	112284	1654	123387	1656
1980	7398	44	83320	849	90717	850
1981	14321	104	79347	309	93669	326
1982	12543	87	77060	346	89604	357
1983	16563	203	80445	491	97007	531
1984	22673	107	76814	456	99486	468
1985	17141	112	90020	419	107160	434
1986	13037	88	99793	541	112829	548
1987	13147	111	117975	662	131122	671
1988	16083	136	82994	510	99077	527
1989	17357	162	101033	694	118390	713
1990	16067	206	99194	646	115261	678
1991	10551	108	99667	676	110218	685
1992	9473	102	86264	623	95737	631
1993	8067	75	81521	664	89589	669
1994	12008	106	86068	872	98076	879
1995	14302	148	69931	523	84232	544
1996	15127	121	75194	573	90320	585
1997	13588	130	78700	544	92288	559
1998	15080	168	85148	678	100228	699
1999	12110	143	92323	661	104433	676
2000	9681	79	83703	658	93384	663
2001	8608	54	82068	721	90675	723
2002	10727	223	69625	412	80352	468
2003	8005	68	57446	457	65451	462
2004	5516	59	44942	348	50458	353
2005	3615	27	26730	214	30345	215
2006	4406	28	35915	235	40321	236
2007	5347	36	34152	210	39499	213
2008	6420	598	27449	125	33869	611
2009	7223	58	32512	157	39735	167
2010	2784	19	25380	140	28164	142
2011	3512	31	23395	126	26907	130
2012	4177	33	32843	180	37021	183
2013	3349	51	24032	146	27381	155
2014	3287	26	32652	256	35939	258
2015	5755	53	21922	188	27677	195
2016	6093	51	25295	146	31388	155
2017	6459	53	24818	161	31277	169

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 (*not separating use/non-use of BRD data run and separating use/non-use of BRD data run*).
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)
Not separating use/non-use of BRD data run		
Dataset	2	Dataset 1 (Observer non-BRD and BRD)
		Dataset 2 (Research vessel)
Separating use/non-use of BRD data run		
Dataset	3	Dataset 1 (Observer non-BRD)
		Dataset 2 (Research vessel)
		Dataset 3 (Observer BRD)

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

Table 7A. Statistics of marginal posterior densities of annual estimates (median) of cobia bycatch (millions of fish) in the eastern Gulf of Mexico shrimp fishery (calendar year and not evaluate BRDs by not separating use/non-use of BRD data run). 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	0.176	0.340	0.007	0.015	0.092	0.784
1973	0.032	0.058	0.001	0.003	0.017	0.147
1974	0.155	0.214	0.005	0.020	0.096	0.632
1975	0.089	0.161	0.003	0.011	0.051	0.397
1976	0.056	0.098	0.002	0.006	0.032	0.250
1977	0.033	0.056	0.001	0.003	0.018	0.152
1978	0.020	0.024	0.001	0.003	0.014	0.076
1979	0.309	0.795	0.016	0.022	0.146	1.559
1980	0.050	0.122	0.002	0.007	0.031	0.187
1981	0.035	0.076	0.002	0.003	0.019	0.161
1982	0.076	0.127	0.003	0.009	0.043	0.349
1983	0.117	0.199	0.004	0.012	0.069	0.510
1984	0.083	0.153	0.003	0.008	0.046	0.376
1985	0.103	0.172	0.003	0.009	0.058	0.488
1986	0.117	0.243	0.005	0.009	0.061	0.546
1987	0.155	0.441	0.007	0.012	0.079	0.760
1988	0.070	0.156	0.003	0.005	0.035	0.337
1989	0.165	0.308	0.005	0.014	0.089	0.779
1990	0.115	0.261	0.004	0.010	0.062	0.538
1991	0.122	0.193	0.004	0.013	0.070	0.555
1992	0.111	0.227	0.004	0.018	0.069	0.427
1993	0.031	0.025	0.000	0.009	0.025	0.090
1994	0.078	0.037	0.001	0.039	0.071	0.164
1995	0.049	0.049	0.001	0.013	0.038	0.154
1996	0.144	0.193	0.004	0.019	0.090	0.617
1997	0.176	0.233	0.005	0.022	0.110	0.727
1998	0.283	0.522	0.009	0.026	0.147	1.350
1999	0.316	0.718	0.012	0.032	0.174	1.399
2000	0.102	0.167	0.003	0.008	0.057	0.484
2001	0.292	0.403	0.007	0.056	0.189	1.127
2002	0.235	0.076	0.001	0.133	0.219	0.424
2003	0.032	0.028	0.001	0.009	0.025	0.098
2004	0.012	0.010	0.000	0.004	0.009	0.033
2005	0.019	0.018	0.000	0.005	0.015	0.061
2006	0.131	0.248	0.004	0.013	0.075	0.578
2007	0.026	0.040	0.001	0.004	0.017	0.102
2008	0.007	0.005	0.000	0.002	0.006	0.018
2009	0.005	0.002	0.000	0.003	0.005	0.010
2010	0.003	0.001	0.000	0.001	0.002	0.005
2011	0.023	0.012	0.000	0.011	0.020	0.050
2012	0.003	0.002	0.000	0.001	0.003	0.008
2013	0.002	0.001	0.000	0.001	0.002	0.006
2014	0.002	0.001	0.000	0.001	0.001	0.004
2015	0.002	0.003	0.000	0.001	0.002	0.008
2016	0.001	0.001	0.000	0.000	0.001	0.003
2017	0.006	0.002	0.000	0.003	0.006	0.012

Table 7B. Statistics of marginal posterior densities of annual estimates (median) of cobia bycatch (millions of fish) in the western Gulf of Mexico shrimp fishery (calendar year and not evaluate BRDs by not separating use/non-use of BRD data run). 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	0.076	0.116	0.003	0.009	0.046	0.317
1973	0.011	0.016	0.000	0.001	0.007	0.045
1974	0.073	0.091	0.003	0.011	0.048	0.269
1975	0.029	0.029	0.001	0.006	0.021	0.102
1976	0.022	0.020	0.000	0.004	0.016	0.070
1977	0.010	0.013	0.000	0.002	0.007	0.036
1978	0.011	0.013	0.000	0.002	0.008	0.042
1979	0.126	0.231	0.006	0.013	0.072	0.558
1980	0.028	0.032	0.001	0.004	0.019	0.109
1981	0.012	0.014	0.000	0.002	0.008	0.047
1982	0.029	0.034	0.001	0.005	0.021	0.106
1983	0.049	0.071	0.002	0.007	0.032	0.190
1984	0.030	0.037	0.001	0.004	0.020	0.113
1985	0.040	0.056	0.001	0.005	0.025	0.170
1986	0.052	0.075	0.002	0.005	0.032	0.230
1987	0.079	0.110	0.002	0.008	0.048	0.350
1988	0.031	0.041	0.001	0.003	0.019	0.132
1989	0.077	0.118	0.002	0.008	0.048	0.318
1990	0.051	0.064	0.001	0.006	0.032	0.206
1991	0.073	0.100	0.002	0.009	0.046	0.288
1992	0.054	0.092	0.001	0.012	0.038	0.182
1993	0.017	0.016	0.000	0.004	0.013	0.050
1994	0.038	0.037	0.001	0.011	0.030	0.118
1995	0.034	0.047	0.001	0.006	0.023	0.132
1996	0.072	0.090	0.002	0.011	0.050	0.272
1997	0.110	0.134	0.003	0.016	0.072	0.417
1998	0.096	0.133	0.003	0.013	0.060	0.412
1999	0.143	0.176	0.004	0.020	0.093	0.552
2000	0.047	0.057	0.001	0.005	0.030	0.192
2001	0.143	0.139	0.002	0.037	0.106	0.471
2002	0.035	0.021	0.000	0.015	0.030	0.086
2003	0.024	0.026	0.001	0.005	0.017	0.085
2004	0.016	0.010	0.000	0.006	0.013	0.039
2005	0.033	0.021	0.000	0.013	0.028	0.082
2006	0.060	0.084	0.002	0.007	0.037	0.248
2007	0.013	0.016	0.000	0.003	0.009	0.047
2008	0.005	0.004	0.000	0.002	0.004	0.014
2009	0.008	0.003	0.000	0.003	0.007	0.016
2010	0.002	0.001	0.000	0.001	0.002	0.004
2011	0.016	0.011	0.000	0.007	0.013	0.043
2012	0.010	0.004	0.000	0.004	0.009	0.020
2013	0.003	0.002	0.000	0.001	0.003	0.007
2014	0.002	0.001	0.000	0.001	0.002	0.004
2015	0.002	0.001	0.000	0.001	0.002	0.005
2016	0.001	0.001	0.000	0.000	0.001	0.003
2017	0.010	0.003	0.000	0.006	0.009	0.017

Table 7C. Statistics of marginal posterior densities of annual estimates (median) of cobia bycatch (millions of fish) in the Gulf of Mexico shrimp fishery (calendar year and not evaluate BRDs by not separating use/non-use of BRD data run). 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	0.289	0.425	0.011	0.036	0.176	1.171
1973	0.055	0.073	0.002	0.006	0.035	0.215
1974	0.256	0.277	0.008	0.046	0.181	0.917
1975	0.143	0.185	0.005	0.025	0.096	0.542
1976	0.106	0.109	0.003	0.026	0.080	0.347
1977	0.055	0.063	0.001	0.010	0.038	0.203
1978	0.049	0.049	0.001	0.010	0.036	0.167
1979	0.581	1.074	0.028	0.066	0.335	2.594
1980	0.272	0.175	0.004	0.113	0.237	0.614
1981	0.067	0.096	0.003	0.010	0.044	0.260
1982	0.156	0.194	0.006	0.026	0.107	0.591
1983	0.214	0.248	0.007	0.036	0.148	0.761
1984	0.156	0.190	0.005	0.022	0.106	0.570
1985	0.182	0.263	0.005	0.024	0.119	0.702
1986	0.202	0.302	0.007	0.022	0.124	0.860
1987	0.291	0.515	0.010	0.033	0.179	1.201
1988	0.135	0.199	0.004	0.014	0.085	0.549
1989	0.288	0.388	0.008	0.035	0.183	1.193
1990	0.223	0.327	0.006	0.029	0.143	0.864
1991	0.241	0.270	0.007	0.034	0.163	0.946
1992	0.513	0.321	0.005	0.210	0.448	1.226
1993	0.158	0.107	0.002	0.056	0.131	0.427
1994	0.132	0.091	0.002	0.063	0.116	0.285
1995	0.117	0.094	0.002	0.038	0.094	0.334
1996	0.343	0.311	0.007	0.086	0.262	1.090
1997	0.418	0.457	0.010	0.070	0.293	1.514
1998	0.499	0.656	0.014	0.072	0.320	1.977
1999	0.548	0.856	0.016	0.079	0.357	2.035
2000	0.186	0.226	0.005	0.022	0.123	0.725
2001	0.629	0.528	0.011	0.201	0.494	1.918
2002	0.278	0.084	0.001	0.163	0.262	0.487
2003	0.114	0.072	0.002	0.043	0.096	0.285
2004	0.045	0.040	0.001	0.016	0.035	0.130
2005	0.077	0.061	0.001	0.026	0.062	0.226
2006	0.210	0.302	0.006	0.029	0.137	0.815
2007	0.048	0.044	0.001	0.017	0.037	0.138
2008	0.014	0.005	0.000	0.008	0.013	0.027
2009	0.018	0.007	0.000	0.010	0.017	0.033
2010	0.006	0.002	0.000	0.003	0.005	0.011
2011	0.036	0.019	0.000	0.020	0.032	0.074
2012	0.012	0.005	0.000	0.006	0.012	0.023
2013	0.009	0.003	0.000	0.005	0.009	0.015
2014	0.003	0.001	0.000	0.001	0.002	0.005
2015	0.005	0.004	0.000	0.002	0.004	0.016
2016	0.005	0.003	0.000	0.002	0.005	0.012
2017	0.014	0.004	0.000	0.009	0.013	0.024

Table 8A. Statistics of marginal posterior densities of annual estimates (median) of cobia bycatch (millions of fish) in the eastern Gulf of Mexico shrimp fishery (calendar year and evaluate BRDs by separating use/non-use of BRD data run). 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	0.532	1.124	0.022	0.043	0.274	2.568
1973	0.094	0.220	0.004	0.008	0.048	0.445
1974	0.408	0.584	0.013	0.054	0.251	1.723
1975	0.211	0.380	0.008	0.028	0.120	0.924
1976	0.120	0.253	0.004	0.014	0.069	0.516
1977	0.069	0.140	0.002	0.007	0.037	0.332
1978	0.041	0.050	0.001	0.007	0.028	0.146
1979	0.871	1.777	0.039	0.071	0.446	4.315
1980	0.099	0.143	0.003	0.014	0.064	0.413
1981	0.080	0.149	0.003	0.008	0.044	0.369
1982	0.208	0.421	0.008	0.023	0.114	0.920
1983	0.347	0.513	0.011	0.042	0.206	1.444
1984	0.232	0.443	0.009	0.024	0.132	0.994
1985	0.299	0.517	0.010	0.026	0.163	1.343
1986	0.352	0.647	0.013	0.027	0.187	1.716
1987	0.442	0.819	0.016	0.036	0.235	2.186
1988	0.199	0.421	0.008	0.015	0.103	0.949
1989	0.460	0.803	0.014	0.040	0.253	2.147
1990	0.314	0.588	0.012	0.028	0.169	1.497
1991	0.370	0.741	0.013	0.038	0.211	1.651
1992	0.168	0.252	0.004	0.027	0.108	0.640
1993	0.040	0.030	0.001	0.012	0.032	0.116
1994	0.105	0.067	0.001	0.047	0.090	0.253
1995	0.077	0.082	0.002	0.020	0.058	0.254
1996	0.309	0.544	0.008	0.038	0.191	1.250
1997	0.439	0.609	0.012	0.057	0.278	1.770
1998	0.625	1.331	0.024	0.055	0.329	2.794
1999	0.301	0.493	0.009	0.032	0.179	1.278
2000	0.110	0.195	0.004	0.009	0.057	0.540
2001	0.139	0.210	0.004	0.021	0.086	0.568
2002	0.166	0.063	0.001	0.087	0.152	0.328
2003	0.020	0.029	0.000	0.005	0.014	0.062
2004	0.009	0.008	0.000	0.003	0.007	0.028
2005	0.015	0.015	0.000	0.003	0.011	0.049
2006	0.129	0.250	0.005	0.013	0.072	0.552
2007	0.025	0.043	0.001	0.004	0.016	0.102
2008	0.007	0.005	0.000	0.002	0.006	0.019
2009	0.005	0.002	0.000	0.003	0.005	0.010
2010	0.003	0.001	0.000	0.001	0.003	0.005
2011	0.022	0.011	0.000	0.011	0.020	0.049
2012	0.003	0.002	0.000	0.001	0.003	0.008
2013	0.002	0.001	0.000	0.001	0.002	0.005
2014	0.002	0.001	0.000	0.001	0.001	0.004
2015	0.002	0.003	0.000	0.001	0.002	0.007
2016	0.001	0.001	0.000	0.000	0.001	0.003
2017	0.006	0.002	0.000	0.003	0.006	0.012

Table 8B. Statistics of marginal posterior densities of annual estimates (median) of cobia bycatch (millions of fish) in the western Gulf of Mexico shrimp fishery (calendar year and evaluate BRDs by separating use/non-use of BRD data run). 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	0.240	0.434	0.010	0.025	0.145	1.045
1973	0.034	0.045	0.001	0.004	0.022	0.136
1974	0.206	0.259	0.006	0.031	0.139	0.775
1975	0.071	0.072	0.002	0.014	0.052	0.257
1976	0.047	0.058	0.001	0.010	0.035	0.154
1977	0.021	0.024	0.001	0.004	0.015	0.077
1978	0.026	0.028	0.001	0.004	0.018	0.085
1979	0.402	0.626	0.016	0.045	0.239	1.734
1980	0.063	0.085	0.002	0.010	0.042	0.246
1981	0.029	0.038	0.001	0.005	0.019	0.111
1982	0.086	0.109	0.003	0.014	0.059	0.306
1983	0.162	0.189	0.005	0.023	0.111	0.601
1984	0.098	0.178	0.003	0.013	0.064	0.368
1985	0.127	0.175	0.004	0.014	0.079	0.535
1986	0.173	0.319	0.007	0.017	0.101	0.743
1987	0.251	0.338	0.008	0.026	0.153	1.078
1988	0.099	0.157	0.003	0.009	0.060	0.420
1989	0.237	0.317	0.007	0.027	0.148	0.959
1990	0.168	0.259	0.006	0.018	0.100	0.704
1991	0.245	0.392	0.007	0.028	0.151	1.016
1992	0.085	0.116	0.002	0.018	0.059	0.296
1993	0.025	0.020	0.000	0.007	0.020	0.078
1994	0.067	0.070	0.001	0.018	0.051	0.218
1995	0.060	0.081	0.002	0.010	0.040	0.240
1996	0.170	0.226	0.004	0.025	0.114	0.642
1997	0.298	0.346	0.007	0.043	0.201	1.138
1998	0.201	0.294	0.005	0.024	0.124	0.818
1999	0.160	0.200	0.004	0.020	0.102	0.615
2000	0.056	0.087	0.002	0.005	0.033	0.243
2001	0.069	0.119	0.002	0.012	0.047	0.255
2002	0.015	0.010	0.000	0.005	0.012	0.041
2003	0.015	0.027	0.000	0.003	0.011	0.051
2004	0.010	0.007	0.000	0.004	0.009	0.027
2005	0.033	0.021	0.000	0.011	0.028	0.086
2006	0.063	0.075	0.002	0.007	0.040	0.260
2007	0.013	0.015	0.000	0.003	0.009	0.046
2008	0.005	0.005	0.000	0.002	0.004	0.017
2009	0.008	0.003	0.000	0.003	0.007	0.016
2010	0.002	0.001	0.000	0.001	0.002	0.004
2011	0.016	0.010	0.000	0.007	0.014	0.041
2012	0.010	0.004	0.000	0.004	0.009	0.020
2013	0.003	0.002	0.000	0.001	0.003	0.007
2014	0.002	0.001	0.000	0.001	0.001	0.004
2015	0.002	0.001	0.000	0.001	0.002	0.005
2016	0.001	0.001	0.000	0.000	0.001	0.003
2017	0.010	0.003	0.000	0.006	0.009	0.018

Table 8C. Statistics of marginal posterior densities of annual estimates (median) of cobia bycatch (millions of fish) in the Gulf of Mexico shrimp fishery (calendar year and evaluate BRDs by separating use/non-use of BRD data run). 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	0.881	1.372	0.033	0.105	0.541	3.723
1973	0.160	0.265	0.006	0.021	0.098	0.644
1974	0.711	0.868	0.022	0.124	0.496	2.550
1975	0.347	0.432	0.010	0.065	0.238	1.293
1976	0.206	0.269	0.005	0.049	0.151	0.666
1977	0.115	0.152	0.003	0.021	0.079	0.424
1978	0.107	0.103	0.003	0.022	0.080	0.367
1979	1.767	2.561	0.073	0.216	1.087	7.504
1980	0.409	0.252	0.006	0.150	0.349	1.022
1981	0.171	0.214	0.006	0.026	0.113	0.683
1982	0.447	0.565	0.014	0.071	0.307	1.623
1983	0.695	0.737	0.021	0.122	0.495	2.502
1984	0.480	0.588	0.015	0.076	0.325	1.806
1985	0.560	0.700	0.017	0.068	0.364	2.249
1986	0.648	0.877	0.022	0.068	0.400	2.685
1987	0.896	1.212	0.031	0.104	0.543	3.755
1988	0.419	0.595	0.014	0.044	0.261	1.749
1989	0.859	1.085	0.023	0.107	0.562	3.357
1990	0.702	1.523	0.030	0.081	0.436	2.809
1991	0.791	1.062	0.022	0.107	0.524	3.122
1992	0.636	0.386	0.006	0.250	0.546	1.564
1993	0.212	0.171	0.003	0.073	0.169	0.611
1994	0.204	0.150	0.003	0.086	0.172	0.508
1995	0.199	0.170	0.004	0.059	0.158	0.613
1996	0.726	1.128	0.018	0.158	0.522	2.458
1997	1.106	1.421	0.029	0.185	0.784	3.929
1998	0.812	1.393	0.027	0.107	0.493	3.198
1999	0.570	0.678	0.015	0.085	0.394	2.073
2000	0.210	0.270	0.007	0.024	0.132	0.863
2001	0.333	0.314	0.006	0.092	0.254	1.053
2002	0.203	0.071	0.001	0.110	0.189	0.379
2003	0.050	0.046	0.001	0.015	0.040	0.140
2004	0.032	0.037	0.001	0.010	0.026	0.088
2005	0.062	0.042	0.001	0.021	0.052	0.161
2006	0.217	0.300	0.007	0.029	0.142	0.829
2007	0.047	0.051	0.001	0.016	0.036	0.136
2008	0.015	0.006	0.000	0.008	0.013	0.029
2009	0.018	0.006	0.000	0.010	0.017	0.032
2010	0.006	0.003	0.000	0.003	0.005	0.012
2011	0.034	0.016	0.000	0.019	0.030	0.071
2012	0.012	0.004	0.000	0.006	0.012	0.023
2013	0.009	0.003	0.000	0.006	0.009	0.016
2014	0.003	0.001	0.000	0.001	0.002	0.005
2015	0.005	0.005	0.000	0.002	0.004	0.015
2016	0.005	0.003	0.000	0.002	0.005	0.012
2017	0.014	0.004	0.000	0.009	0.014	0.024

Table 9. Statistics of marginal posterior densities of the grand median of annual median estimates (1972-2017) of cobia 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 and run	Mean	SD	MC error	2.50%	Median	97.50%
Eastern GOM: Not Evaluate BRDs	0.036	0.010	0.000	0.021	0.034	0.059
Western GOM: Not Evaluate BRDs	0.020	0.004	0.000	0.013	0.019	0.030
GOM: Not Evaluate BRDs	0.094	0.023	0.001	0.057	0.091	0.147
Eastern GOM: Evaluate BRDs	0.067	0.019	0.001	0.038	0.064	0.110
Western GOM: Evaluate BRDs	0.035	0.009	0.000	0.021	0.033	0.055
GOM: Evaluate BRDs	0.172	0.040	0.002	0.109	0.167	0.263

Table 10. Annual bycatch (median in millions of fish) of cobia in the Gulf of Mexico shrimp fishery for the previous SEDAR 28 (updated estimates in June 2012 from the Data Workshop estimates in Feb 2012 (Linton 2012) and the updated values were used in the stock assessment model) and current SEDAR 28 Update runs (calendar year).

Year	SEDAR 28: GOM (Not Eval BRDs)	SEDAR 28 Update: GOM (Not Eval BRDs)	SEDAR 28 Update: GOM (Eval BRDs)
1972	0.226	0.176	0.541
1973	0.042	0.035	0.098
1974	0.282	0.181	0.496
1975	0.129	0.096	0.238
1976	0.106	0.080	0.151
1977	0.044	0.038	0.079
1978	0.042	0.036	0.080
1979	0.445	0.335	1.087
1980	0.285	0.237	0.349
1981	0.057	0.044	0.113
1982	0.165	0.107	0.307
1983	0.203	0.148	0.495
1984	0.143	0.106	0.325
1985	0.162	0.119	0.364
1986	0.150	0.124	0.400
1987	0.221	0.179	0.543
1988	0.101	0.085	0.261
1989	0.196	0.183	0.562
1990	0.174	0.143	0.436
1991	0.189	0.163	0.524
1992	0.586	0.448	0.546
1993	0.167	0.131	0.169
1994	0.165	0.116	0.172
1995	0.120	0.094	0.158
1996	0.412	0.262	0.522
1997	0.495	0.293	0.784
1998	0.376	0.320	0.493
1999	0.491	0.357	0.394
2000	0.151	0.123	0.132
2001	0.456	0.494	0.254
2002	0.209	0.262	0.189
2003	0.099	0.096	0.040
2004	0.045	0.035	0.026
2005	0.087	0.062	0.052
2006	0.177	0.137	0.142
2007	0.047	0.037	0.036
2008	0.013	0.013	0.013
2009	0.019	0.017	0.017
2010	0.006	0.005	0.005
2011	0.041	0.032	0.030
2012	0.012	0.012	0.012
2013		0.009	0.009
2014		0.002	0.002
2015		0.004	0.004
2016		0.005	0.005
2017		0.013	0.014

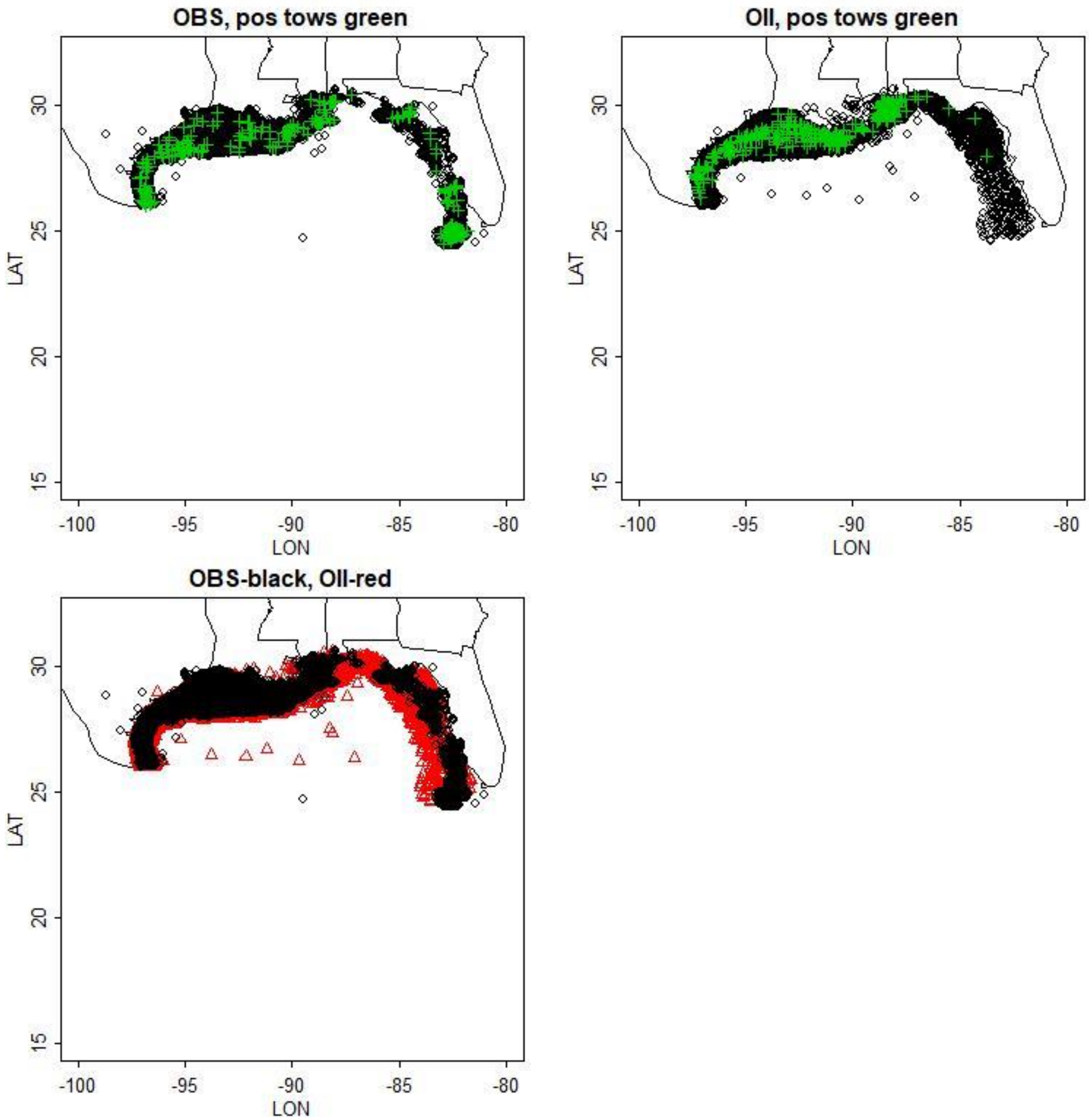

Figure 1. Spatial plots of shrimp observer data and Oregon II SEAMAP data with positive tows shown in green and overlap of Oregon II SEAMAP (red) and Observer (black).

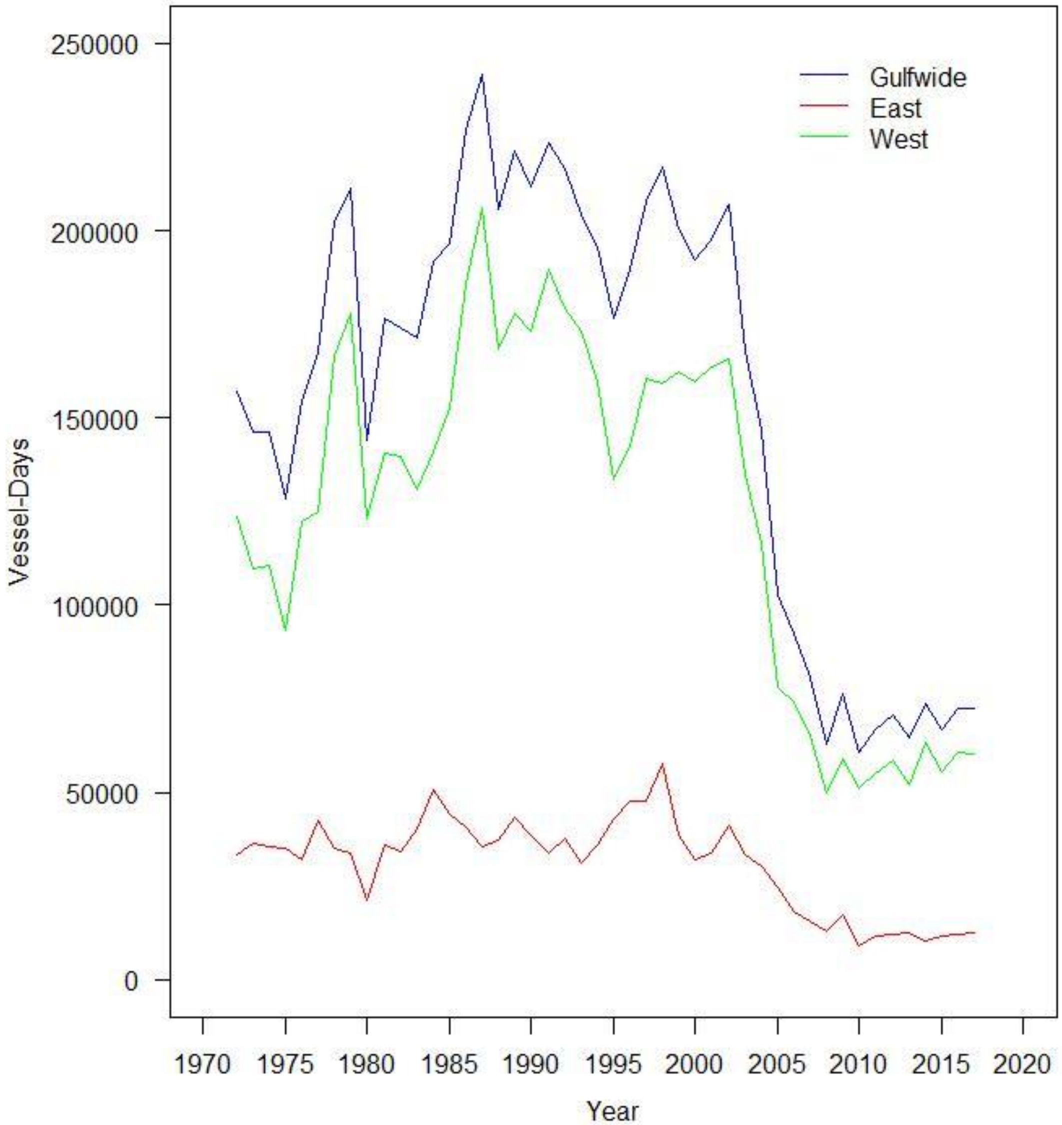

Figure 2. Gulf of Mexico shrimp fishery effort (vessel-days) provided by the NMFS Galveston Lab (calendar year).

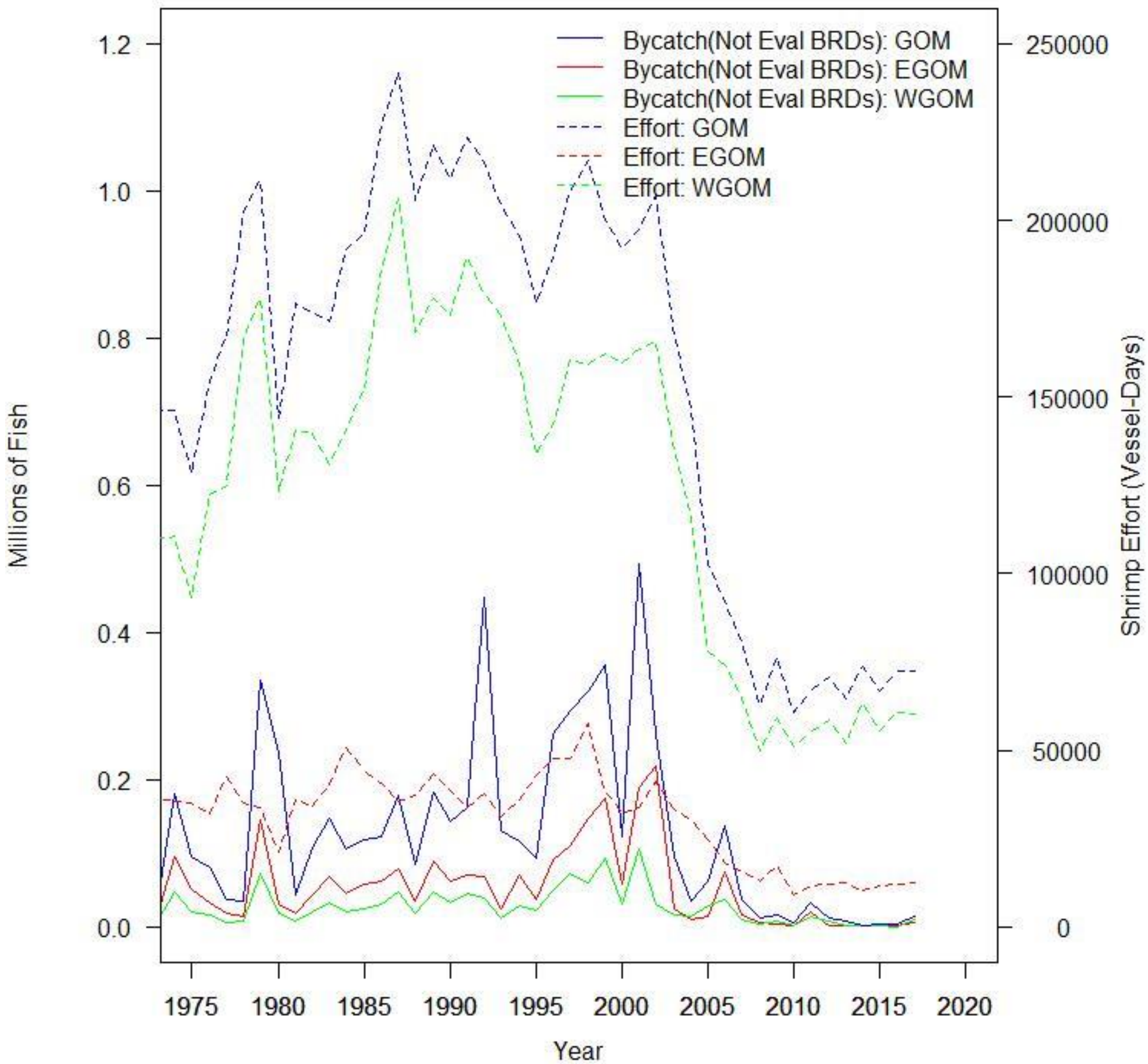

Figure 3A. Annual bycatch (median in millions of fish) of cobia in the Gulf of Mexico shrimp fishery and shrimp fishery effort (vessel-days) provided by the NMFS Galveston Lab (calendar year and not evaluate BRDs by not separating use/non-use of BRD data run).

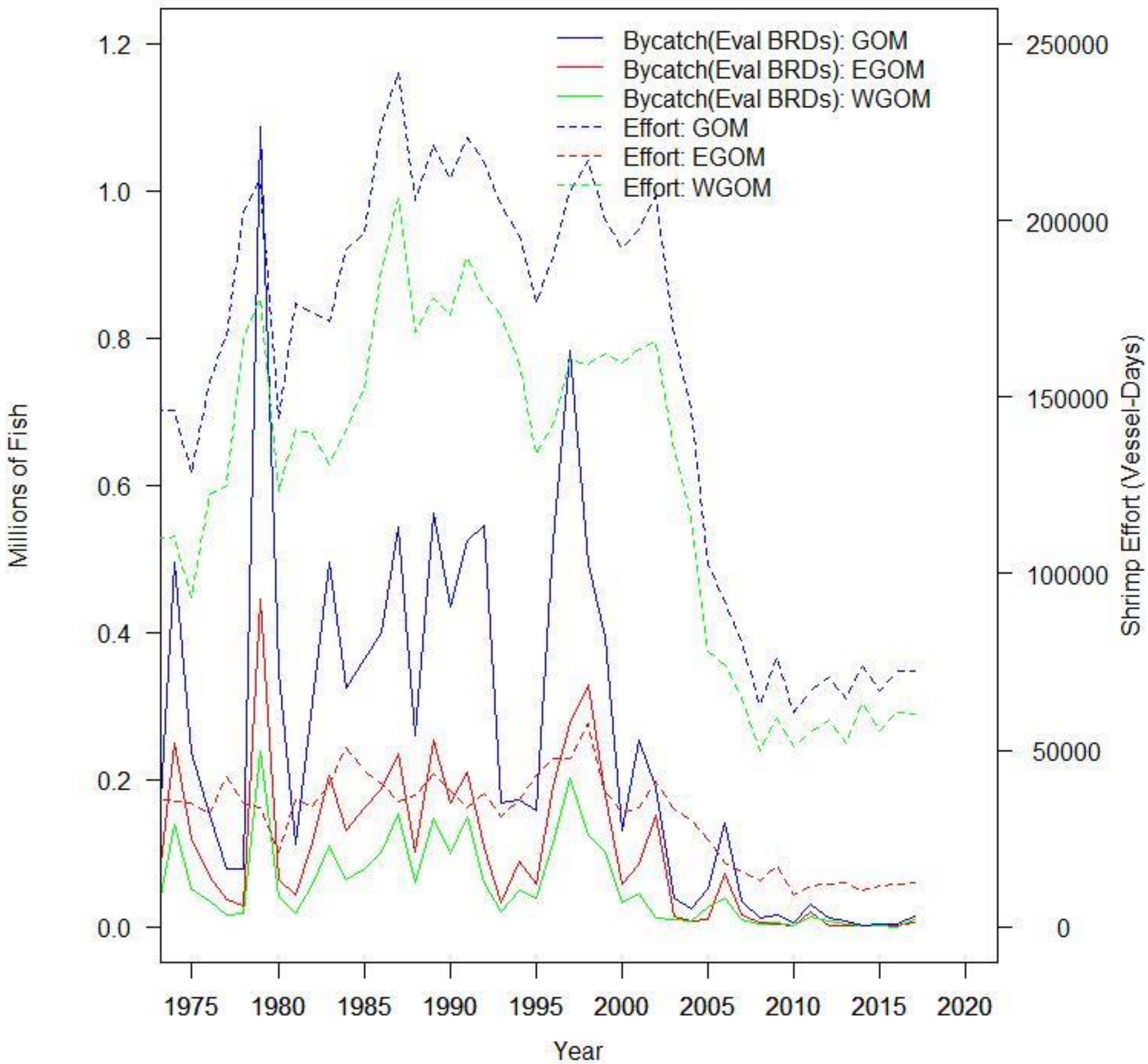

Figure 3B. Annual bycatch (median in millions of fish) of cobia in the Gulf of Mexico shrimp fishery and shrimp fishery effort (vessel-days) provided by the NMFS Galveston Lab (calendar year and evaluate BRDs by separating use/non-use of BRD data run).

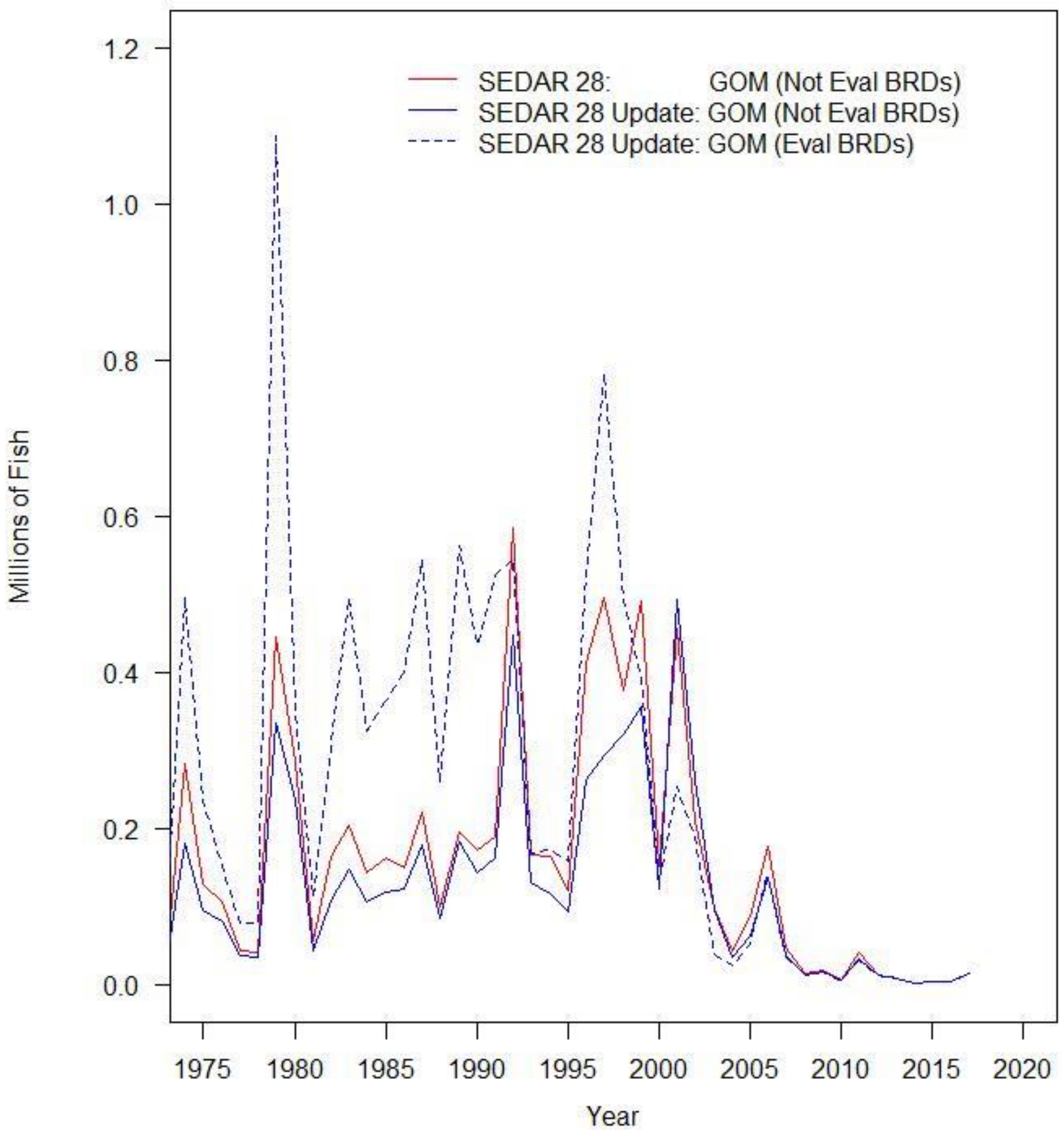

Figure 4. Annual bycatch (median in millions of fish) of cobia in the Gulf of Mexico shrimp fishery for the previous SEDAR 28 (updated estimates in June 2012 from the Data Workshop estimates in Feb 2012 (Linton 2012) and the updated values were used in the stock assessment model) and current SEDAR 28 Update runs (calendar year).

Appendix A. WinBUGS code for the 3-season, 4-area, 3-depth zone, 2-dataset (not evaluate BRDs by not separating use/non-use of BRD data run), error-in-effort and error-in-nets-per-vessel models used in SEDAR 28 Update.

```
model  GOM Cobia_3dp_2dset_h86777 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, VS and Cobia, so h is much smaller
#Zhang do GOM Cobia: fishing year= calendar year
#Zhang season 1=Jan-Apr, season 2=May-Aug, season 3=Sept-Dec
#Zhang NOT included BRD effect (see SEDAR7-DW-54 test 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 0.05 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, vermilion snapper, and cobia
# 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 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 years, 1972-2017
  yx[i]~dnorm(-1,0.7)               #Zhang Cobia year prior from SEDAR9AW3 same as VS, GT, KM, 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. CobiaBYCATCH_3DP_2DSET_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 1:86777) {                                                         #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 Cobia
#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 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
}
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
```

Appendix B. WinBUGS code for the 3-season, 4-area, 3-depth zone, 3-dataset (evaluate BRDs by separating use/non-use of BRD data run), error-in-effort and error-in-nets-per-vessel models used in SEDAR 28 Update.

```
model  GOM Cobia_3dp_3dset_h86777 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, VS and Cobia, so h is much smaller
#Zhang do GOM Cobia: fishing year= calendar year
#Zhang season 1=Jan-Apr, season 2=May-Aug, season 3=Sept-Dec
#Zhang included BRD effect (see SEDAR7-DW-54 test and Appendix)
#Zhang report bycatch for 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 0.05 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, vermilion snapper, and cobia
# 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 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 years, 1972-2017
  yx[i]~dnorm(-1,0.7)                #Zhang Cobia year prior from SEDAR9AW3 same as VS, GT, KM, 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. CobiaBYCATCH_3DP_3DSET_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 1:86777) {                                              #Zhang need to update the end h
  lamb[h]~dgamma(r,mu[yr[h],seas[h],ar[h],dp[h],ds[h]])
  lambda[h]<-lamb[h]*hrsfishd[h]
  catch[h]~dpois(lambda[h])
  }

#Zhang take (i.e. bycatch) for 1972-1997 (i.e. i=1:26), prior mandatory BRD, use no-BRD_CPUE 1 (i.e. y[i,j,k,l,1])
for (i in 1:26)  {
  for (j in 1:3)   {
    for (k in 1:4)  {
      for (l in 1:3)  {
        effort[i,j,k,l]~dnorm(effmean[i,j,k,l],efftau[i,j,k,l])              #Zhang shrimp effort
        npv[i,j,k,l]~dnorm(voufmean[i],vouftau[i])                           #Zhang net per vessel
        take[i,j,k,l]<-y[i,j,k,l,1]*npv[i,j,k,l]*effort[i,j,k,l]             #Zhang take stands for estimated bycatch
        }
      }
    }
  }

#Zhang take (i.e. bycatch) for 1998 (i.e. i=27), phased in mandatory BRD year, HARD CODED
#Zhang season 1, all areas and depths use no-BRD_CPUE 1 (i.e. y[27,1,k,l,1])
    for (k in 1:4)  {
      for (l in 1:3)  {
        effort[27,1,k,l]~dnorm(effmean[27,1,k,l],efftau[27,1,k,l])
        npv[27,1,k,l]~dnorm(voufmean[27],vouftau[27])
        take[27,1,k,l]<-y[27,1,k,l,1]*npv[27,1,k,l]*effort[27,1,k,l]
        }
      }
#Zhang season 2, area 1 and all depths, use no-BRD_CPUE 1 (i.e. y[27,2,1,l,1])
      for (l in 1:3)  {
        effort[27,2,1,l]~dnorm(effmean[27,2,1,l],efftau[27,2,1,l])
        npv[27,2,1,l]~dnorm(voufmean[27],vouftau[27])
        take[27,2,1,l]<-y[27,2,1,l,1]*npv[27,2,1,l]*effort[27,2,1,l]
        }
#Zhang season 2, areas 2-4 all depths, use BRD_CPUE 3 (i.e. y[27,2,k,l,3])
     for (k in 2:4)  {
      for (l in 1:3)  {
        effort[27,2,k,l]~dnorm(effmean[27,2,k,l],efftau[27,2,k,l])
        npv[27,2,k,l]~dnorm(voufmean[27],vouftau[27])
        take[27,2,k,l]<-y[27,2,k,l,3]*npv[27,2,k,l]*effort[27,2,k,l]
        }
      }
#Zhang season 3, all areas and depths, use BRD_CPUE 3 (i.e. y[27,3,k,l,3])
    for (k in 1:4)  {
      for (l in 1:3)  {
        effort[27,3,k,l]~dnorm(effmean[27,3,k,l],efftau[27,3,k,l])
        npv[27,3,k,l]~dnorm(voufmean[27],vouftau[27])
        take[27,3,k,l]<-y[27,3,k,l,3]*npv[27,3,k,l]*effort[27,3,k,l]
        }
      }

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

```
      }
     }
    }
   }

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

#Zhang East and West annual
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 Cobia
#for (i in 1:46) {                                   #Zhang need to update the end year
#   for (j in 1:3)    {
#    trimester[i,j]<-sum(take[i,j,,])                #Zhang season specific GOM annual
#   }
#}

#Zhang Gulfwise, East, West median of annual medium (i.e. mofam), 46, so use average 23 and 24
mofam<-    (ranked(annual[1:46],23) + ranked(annual[1:46],24))/2
mofamE<-  (ranked(annualE[1:46],23) + ranked(annualE[1:46],24))/2
mofamW<- (ranked(annualW[1:46],23) + ranked(annualW[1:46],24))/2
}
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
```