Updated Estimates of Gulf king mackerel bycatch from the U.S. Gulf of Mexico Shrimp trawl fishery

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Summary

This manuscript documents the procedures and methodologies used during the 2008 stock evaluation of king mackerel for estimating bycatch from the U.S. Gulf of Mexico Shrimp trawl fishery. Gulf king mackerel bycatch were estimated using two alternative models for the period 1972 through 2006. The two methods include a Generalized Linear Model (GLM) (Nichols et al. 1987), and the delta lognormal model (Ortiz et al. 2000). Both methods estimate a mean bycatch rate per unit of shrimp effort (hour tow) for a *Year, Area, Season, depth zone*, and *Source type* stratum. Total bycatch is then estimated as the product of the mean bycatch rate times the corresponding estimated shrimp fishing effort in a particular stratum. Annual bycatch for king mackerel is calculated as the sum of the corresponding bycatch of the commercial sector over all areas, seasons and depth zones. The models account for the introduction of bycatch reduction devices (BRD) since 1998, as well the requirements of BRD use by area and season distribution. The king mackerel bycatch is assumed to be age-0 class.

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Introduction

The main objective of this manuscript is to document the procedures and methodologies used during the 2008 stock evaluation of king mackerel for estimating shrimp bycatch in the US Gulf of Mexico. Bycatch of king mackerel in the Gulf of Mexico shrimp trawl fishery has been recognized as a source of indirect fishing mortality for this stock (MSAP 1998, MSAP 2000, MSAP 2003, SEDAR5). The bycatch is computed as the product of the catch rate (CPUE) and total shrimp effort, which are estimated independently using a common framework to group similar strata. This species is encountered rarely by observers on board of commercial shrimp vessels and research trawls, but the large amount of shrimp fishing effort produced large estimates of total bycatch. The general pattern of the data, as in with most bycatch species, is a large percent of zero catch with few positive catch observations, which tend to have very large variability (Ortiz and Legault 1998).

A generalized linear model (GLM) has been traditionally used to estimates the annual bycatch of several species including king mackerel, from the US Gulf shrimp fishery (Nichols et al. 1987). This method assumes that the distribution of the logarithmic transformed catch per unit of effort (CPUE) of king mackerel is normally distributed, to avoid the problem on undefined logarithms; a constant value of one is added to all nominal CPUEs. An alternative method, the delta lognormal model has been proposed, that separates the analysis of zero and non-zero nominal CPUE (Ortiz et al. 2000). The latest approach treats the values as two-part process, the probability of encountering a positive value (i.e. a shrimp tow with a king mackerel), and the expected mean catch rate given that a positive value was encountered.

Nichols (2004 and 2004a) presented an alternative estimation model of shrimp bycatch using Bayesian techniques for red snapper and king mackerel in 2004. These documents also reviewed the criticism and limitations of the bycatch estimation procedures, included uncertainty in the shrimp fishing effort estimates, and reviewed the available information regarding the average number of nets in the shrimp fleet.

Materials and Methods

Data for bycatch estimation comes from two main sources, observers aboard commercial shrimp vessels and surveys from research vessels that use commercial shrimp nets and operate in areas where commercial fishing take place. Ideally, all estimates should be restricted to observer data. However due to coverage limitations, annual continuity of observer programs and personnel and resource restrictions, it is not possible to generate annual series of bycatch relying only on observer data. In response to the large proportion of fish bycatch in the U.S.

Gulf of Mexico shrimp fishery, in 1996/97 shrimp trawls required the used of approved bycatch reduction devices (BRDs) to reduce fish bycatch mortality (Foster 2004). This measure obviously impacts the estimation of Gulf king mackerel bycatch from 1997 on. Several studies were and are being carried out to evaluate the effectiveness of BRDs and to improve the characterization of the bycatch in this fishery (NMFS Southeast Regional Office 1995). At the present several data sets comprise the database for bycatch estimation, including:

1. OREGON II research data. This data represents research tows using commercial shrimp nets, in a defined sampling protocol that covers most of the east and western Gulf shrimp fishing grounds (GSMFC 2001). The data includes research tows from the SEAMAP sampling program, and the GroundFish Survey program. It covers from 1972 through 2001 and constitutes the main linkage between several observer programs that are discontinuous throughout the years.
2. Old observer data. This data is a compilation of several programs that collected information of fish bycatch aboard commercial shrimp vessels from 1972 through 1994 (Nichols *et al.* 1987, Ortiz *et al.* 2000).
3. Regional Research Program. This data includes a research sampling program initiated in 1992 through 1997, aimed to characterized bycatch in both the Gulf of Mexico and the South Atlantic shrimp fisheries. The programs also expanded to test and evaluate different types of BRDs during normal shrimp fishing operations (Hoar et al. 1992).
4. Summer 1998 data. This data includes information for shrimp trawls with BRD (evaluation), and control nets. This data differs from the regional research program in that emphasis of bycatch identification/ quantification is for a selected number of species, primarily red snapper (SEFSC 1999).
5. Modern data. This data includes data collected on commercial vessels by observers since 2000. Scott-Denton (2004) provided a review of all observer activity since the start of the Regional Research Program in the early 1990s. The new modern observer data come from multiple projects. Nichols (2004a) describe which projects were included for the estimation of red snapper bycatch, briefly most of the BRD /noBRD paired tows, with data in separate 'experimental' (BRD) and 'control' (noBRD) files. Detailed review of each record was done before for red snapper (coded as "archived", Nichols 2004a), however that has not been the case for other species including king mackerel. Therefore, this document included all records available from the Galveston database from the modern observer data that reported catches of king mackerel without a further review of each record.

The data is structured into two main files; a station or tow file which records time, location, and duration of the tow, plus a set of fishery and environmental related variables, and a bycatch composition file, which records numbers and size of the bycatch in each station, by species. Overall available bycatch data covers from 1972 through 2006.

The second component for bycatch estimation is the shrimp fishing effort. This data is estimated and provided by Rick Hart at the Galveston laboratory (NMFS Galveston lab). The updated shrimp fishing effort files were available from 1981 forward and include area, depth zone, and an estimate of error. In order to extend the king bycatch time series back to 1972, it was decided to joined previous estimates of shrimp effort from 1972-1980 (available from the 2002 estimation files), with the new shrimp effort 1981-2006 files.

The current stratification scheme for bycatch estimation includes: 3 data set types, research, commercial and BRD observations; 3 seasons, Jan-Apr, May-Aug, and Sep-Dec; 4 areas, Florida West coast and the Florida Keys, Mississippi – Alabama, Louisiana, and Texas coast; 2 depth zones, less or equal to 10 fathoms, and more than 10 fathoms; and 35 years, from 1972 to 2006. The same stratification scheme was used for the GLM and the delta lognormal model.

Nominal bycatch rates (CPUE) were estimated as numbers of king mackerel per one-hour tow time. In the case of the GLM the observed log-transformed catch rates plus one are modeled as:

$$\log_{10}\left(CPUE_{ijklm}+1\right)=Year_i+Data\ type_j+Season_k+Area_l+Depthzone_m+\varepsilon_{ijklm}$$

where ε assumed a normal error distribution. Predicted catch rate is then estimated as:

$$\begin{aligned}&if\ C\hat{P}UE_{ijklm}\geq 0\ then\ C\hat{P}UE_{ijklm}=10^{(\hat{Y}+1.1513*\sigma^2)}-1\\&else\ C\hat{P}UE_{ijklm}=0\end{aligned}$$

where $\hat{Y}$ is the predicted estimates for each *Year(i) data-type(j) season(k) area(l) depthzone(m)* stratum, and σ^2 the estimated variance of the model. Estimates of variance for the predicted catch rates are calculated as:

$$\begin{aligned}&K=5.302*\sigma_{se}{}^2\\&C=14.0554*\sigma^2/df\\&Var=\left(C\hat{P}UE_{ijklm}+1\right)^2*\left(K+C-K*C\right)\end{aligned}$$

where $\sigma_{se}{}^2$ is the standard error of the predicted catch rates. (A. Shah, in Nichols et al. 1987). Once, the predicted bycatch rates are computed, estimated bycatch is the product of the bycatch rate of the commercial (or BRD) times the shrimp effort for each *Year season area depthzone* stratum of the commercial *data type*. Thus, estimated annual bycatch is simply the sum over each year of estimated bycatch by area season and depthzone for the commercial (or BRD) sector (s).

$$Bycatch_i = 2*24*\sum_{klm\,j*} C\hat{P}UE_{iklm} * f_{iklm}$$
$$for\ j^* = commercial\ or\ BRD$$

where f_{iklm} is the shrimp fishing effort for year *i*, season *k*, area *l* and depthzone *m.* The value 2 represents the assumed average number of shrimp trawl nets per vessel, and the value 24 is a factor for converting hour estimates to fishing day estimates. From 1997 on, the estimates of bycatch use the predicted BRD for those area season combinations were BRDs were 'mostly' required, and the predicted commercial rates for those area season combinations were BRDs were not required. Here, the 'mostly' required area/season strata are an approximation of the BRD boundaries definition as they do not match exactly (S. Nichols, personal communication, SEFSC 1999).

In the case of the delta model approach, the estimates of mean bycatch rate for the same stratification scheme is split into two components: one, the estimate of the probability of encounter (as bycatch) at least one king mackerel, and two the mean catch rate if there is at least one fish caught (Ortiz et al. 2000). The first component or proportion of successful tows (*y*) per stratum is assumed to follow a binomial distribution, such as

$$f(y) = \binom{n}{r} p^r (1-p)^{n-r}$$

where *n* is the total number of tows per stratum, *r* is the number of tows that caught king mackerel (i.e positive tows), and *p* the probability to estimate. Using generalized linear model theory; the estimated proportion can be modeled as a linear function of the fixed factors *Year data-type season area* and *depthzone*, as

$$\eta_{ijklm} = Year_i + Datatype_j + Season_k + Area_l + Depthzone_m$$

where η_{iklm} is the linear predictor, and relates to the binomial error assumed distribution through a link function, in this case the probit function, such as

$$\eta_{ijklm} = \Phi^{-1}\left(p_{ijklm}\right)$$

where $\hat{p}_{iklm}$ is the estimated proportion of positives by stratum. For the positive tows, estimated catch rates were assumed to follow a lognormal distribution of a linear function of the same fixed factors.

$$\log\left(CPUE'_{ijklm}\right) = Year_i + Data\ type_j + Season_k + Area_l + Depthzone_m + \varepsilon_{ijklm}$$

Then the estimated mean bycatch rate per stratum is estimated as the product of the predicted proportion of positive tows times the mean catch rate for positive tows. The estimation of bycatch in numbers of king mackerel follows the same procedure as in the GLM case:

$$Bycatch_i = 2*24*\sum_{klm\ j*} \hat{p}_{iklm} * C\hat{P}UE'_{iklm} * f_{iklm}$$
$$for\ \ j^* = commercial\ or\ BRD$$

where $C\hat{P}UE'_{iklm}$ is the conditional mean bycatch rate.

The observer data from 1994 forwards includes bycatch characterization data, and evaluation of BRDs data. The protocols for the BRD evaluation tows specified pair-net trawling; one net with the BRD and a second control net, to evaluate variability among tows (GSAFDF 1995). In addition, the sampling design protocols of the new observer programs were different from those of the older observed data (*i.e.* prior to 1994). Therefore, it is possible with the new observer data to extract different subsets of data, depending if control nets were included or not, and to join or not this data with the old observer data. For evaluation different bycatch estimation models were considered depending, upon which observer subset data was included or not.

Under this scheme, the following models were specified:

1. Old observer data exclusively. This dataset include the Oregon II observations (research data) and the observer programs data prior to 1994.
2. New observer characterization data only. This dataset include the Oregon II research data and the characterization tows data from the Regional Research Program and the Summer 98 program.
3. All observer data without BRDs. This dataset include the Oregon II, old observer programs, and both the characterization data and control nets data from the Regional Research Program and the Summer 98 Program.
4. BRD observer data. This dataset include the Oregon II and observer data from tows using approved BRDs in both the Regional Research Program and the Summer 98 Program.
5. All observer data. This dataset include the Oregon II, the old observer data, the characterization, evaluation and BRD data from the Regional Research Program and the Summer 98 Programs.
6. All observer data with BRDs as a third category level for data type. This dataset include the Oregon II, the old observer data, characterization and controls only data from both the Regional Research Program and the Summer 98 Programs. It differs from model 5, as the predicted bycatch is sum over data type BRD exclusively.

7. Actual Situation. This model is the same as model 5 (model 5A). The difference is the actual estimation of annual bycatch, where for the year 1997-2001, for those combinations for area season where there is a requirement of have BRDs, the estimates use the BRD predicted catch rates, while for those area season combinations that do not required BRD, it uses the commercial predicted catch rates.

Results and Discussion

Table 1 shows the summary of annual bycatch estimates for Gulf king mackerel from each of the six models (1-6) and the "actual" or best estimate using the GLM approach. Table 2 shows similar results for the Delta lognormal approach. The delta models did not provided king bycatch estimates for 1983, as there was not a single tow that reported catching king mackerel in 1983 from the observer or research datasets. Figure 1 shows a comparison of the best estimates GLM model from the 2000, 2003 and (2008) current stock assessment evaluations. Prior to 1997, trends were similar between estimates, the absolute values changed in 2008, mainly due to changes in the estimates of shrimp fishing effort between 2002 and 2008. After 1997 the trend changes as well the magnitude between 2008 and prior estimates. This difference is due to the effect of modern BRD catch rates. BRD observations from 1994 through 1998 were a series of experimental trials, and evaluation performance of more than 40 BRD designs. Most of those BRDs were rejected either because of no reduction in bycatch or main target species, or because of large reductions of shrimp catch. During the 1994-98 trials, tested BRDs indicated that king mackerel bycatch was reduced by about 60-70%. However, observations collected since 2000 on shrimp vessels with approved BRDs indicated that the bycatch of king mackerel increased again. In some instances, nets with BRD were having greater retention of king compare to control nets. The net effect is that BRD have similar catch rates as control nets and actual estimates of bycatch have increased in recent years, until 2004, when the overall shrimp effort started to decrease substantially in the GOM shrimp fleet.

The delta model bycatch estimates area always greater and have more annual variation compared to the GLM model estimates (Fig 2). For stock management information, the "actual" situation estimates were chosen as the most likely scenario; as this model takes into account differential effects of BRDs as well as the season-area requirement of BRD implementation. In as much that stock evaluations required estimates of bycatch, in particular from the shrimp fishery, this does not imply that the methods and estimations for shrimp bycatch of Gulf king mackerel or other species are the optimal methodologies. It is important to bring some of the limitations and assumptions that apply to both approaches for estimating bycatch. For example, although the BRDs are grouped into a single category, in reality BRDs are a group of highly diverse designs models and gear modifications (GSAFDF 1995). It is impossible to include each type/configuration BRD in an overall bycatch estimation model.

Thus, in this case at least, BRD level represents simple an estimated average of several tested BRD types. Another assumption is the mean number of trawl nets per boat (two) which likely underestimates the total bycatch, as in the latest years the mean number is likely to be higher (Nichols, 2004a), Ortiz et al (2001) also, commented on the average tow time between research tows (i.e. the *R/V* Oregon II) and the commercial shrimp vessels, which likely reflect very different selectivity or efficiency patterns in the observed bycatch rates. Of concern also, is the lack of sufficient contrast between levels in a category factor, as in BRD and non-BRD trawls. As the implementation/requirement of BRDs took place in a very short time period, this restricted the possibility of interactions which confounds the analyses. Finally, shrimp fishing effort is assumed to be known without error in this model (see Nichols 2004 for a model implementation that account for uncertainty in the shrimp effort estimates), although Nichols (2004a) concluded that uncertainty of bycatch rates are the dominant feature in the trends of bycatch, compared to the uncertainty of shrimp fishing effort .

Finally, restating the discussion from Nichols (2004a), continuing with indirect models to test for the effects of BRD implementation particularly in years without direct observations is highly uncertain particularly when the BRD is really a sum of very different experimental designs, fishing operation procedures, learning and experience, and multiple confounding factors. Foster (2004) reported on the performance of the approved BRD's that likely are currently used by the shrimp fleet. As of 2004, the BRDs performance is highly correlated with the cost and operational complexity, and fishers have learned to minimize shrimp loss at the cost of reducing the effectiveness of the BRD (Foster 2004). This effect is apparent in the case of king mackerel; Figure 3 shows the nominal catch rates for all BRD observations (mean by year) versus the control nets. Nominal catch rates of non BRD sets and BRD sets for king mackerels are similar in the modern observer data, this figure also show that the proportions of tows encounter king mackerel increased in 2004/05 from 2% to 8%. These catch rates were substantially different compare to the early BRD data, that suggested reductions of king bycatch of 60% or more.

Because the modern BRD data is likely to reflect the current status of the shrimp fleet, estimates of bycatch were calculated using only the modern BRD data. Table 3 and Figure 4 show the estimates of bycatch for the GLM and delta models when including or not the BRD early data.

Addendum

An assumption of the analysis presented above is that the average number of nets per shrimp vessel is 2. This assumption was used in the prior (SEDAR 5) estimates of shrimp bycatch for king mackerel and other species, although it has been recognized that the mean number of nets per vessel has likely increased over time. Nichols (2004a) used the Vessel Operating Unit File (VOUF) to estimate mean number of nets by year that was later used in estimates of bycatch for red snapper. Figure 5 shows the annual trend of average number of nets: From 1.87 in 1972, it has increase steadily to 3.1 nets per vessel in 2006. Because the number of nets is a constant multiplier for the shrimp effort, this increase will effectively raise the shrimp effort by that factor. This would then assume that a vessel with 3 or 4 nets will have 3 or 4 times the fishing power of a vessel with a single net.

Provided this, the king mackerel shrimp bycatch was re-estimated using the average number of nets per year. Table 3 and Figure 6 show the new estimates corresponding to the model 5A, best estimates of bycatch using the BRD modern data only for the GLM and delta models.

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Table 1. Estimates of king mackerel Gulf bycatch from the GLM model (millions of fish). See text for descriptions of models 1 to 6, actual column refers to the 'best' estimates of bycatch.

Year	GLM Model 1	GLM Model 2	GLM Model 3	GLM Model 4	GLM Model 5	GLM Model 6	GLM Actual
1972	0.935672	0.691118	0.831196	0.327436	0.705842	0.564519	0.705842
1973	0.393716	0.247856	0.322685	0.027847	0.247241	0.157784	0.247241
1974	0.50717	0.327277	0.410769	0.0511	0.270067	0.174134	0.270067
1975	0.367919	0.219834	0.307701	0.026406	0.233509	0.154414	0.233509
1976	0.417961	0.235714	0.34889	0.015496	0.261705	0.162956	0.261705
1977	0.418244	0.242111	0.337208	0.014313	0.259631	0.155935	0.259631
1978	0.65886	0.418255	0.599743	0.075127	0.497721	0.348775	0.497721
1979	0.7983	0.507402	0.646148	0.130427	0.500383	0.342389	0.500383
1980	0.496977	0.338444	0.416041	0.043593	0.349756	0.227314	0.349756
1981	0.495843	0.285681	0.421846	0.019014	0.348856	0.226478	0.348856
1982	0.488756	0.295121	0.406499	0.027331	0.323607	0.206646	0.323607
1983	0.459194	0.279461	0.378685	0.021952	0.302353	0.190302	0.302353
1984	0.667215	0.44458	0.57053	0.101271	0.461273	0.322033	0.461273
1985	0.668661	0.428485	0.552441	0.092125	0.438211	0.298902	0.438211
1986	0.600888	0.319246	0.445317	0.015994	0.302963	0.169169	0.302963
1987	1.100061	0.773945	0.919473	0.277956	0.702523	0.513385	0.702523
1988	0.82432	0.538634	0.666434	0.156468	0.496395	0.343557	0.496395
1989	1.594211	1.265614	1.411351	0.787739	1.213507	1.023645	1.213507
1990	1.142799	0.85198	0.985254	0.399154	0.798454	0.625294	0.798454
1991	1.366837	1.0483	1.192901	0.569315	0.996273	0.808184	0.996273
1992	0.739444	0.533347	0.598314	0.07518	0.495614	0.336786	0.495614
1993	1.403796	1.090939	1.13596	0.570824	1.021193	0.84727	1.021193
1994	1.219114	0.937186	0.995192	0.5396	0.936745	0.77091	0.936745
1995	1.402221	1.100201	1.164836	0.716916	1.039193	0.88647	1.039193
1996	0.837643	0.579098	0.672634	0.199414	0.54453	0.39937	0.54453
1997	1.042763	0.734394	0.844265	0.313993	0.690749	0.524512	0.690749
1998	1.178276	0.799823	0.908896	0.413642	0.726512	0.552667	0.591602
1999	1.032952	0.744857	0.87003	0.331736	0.692199	0.53072	0.53072
2000	1.155357	0.87955	1.003753	0.463258	0.824753	0.663543	0.663543
2001	1.441188	1.134795	1.269963	0.588802	0.696527	0.535527	0.535527
2002	0.957639	0.660313	0.790121	0.48876	0.676045	0.510337	0.510337
2003	1.530392	1.26331	1.381521	0.577631	0.687473	0.546907	0.546907
2004	1.569796	1.33235	1.436178	0.950219	1.10672	0.975943	0.975943
2005	0.576551	0.429827	0.492909	0.550368	0.697712	0.607286	0.607286
2006	0.654717	0.535133	0.58631	0.349516	0.490011	0.42326	0.42326

Table 2. Estimates of king mackerel Gulf bycatch from the Delta lognormal model (millions of fish). See text for descriptions of models 1 to 6, actual column refers to the 'best' estimates of bycatch.

Year	DELTA Model 1	DELTA Model 2	DELTA Model 3	DELTA Model 4	DELTA Model 5	DELTA Model 6	DELTA Actual
1972	5.1686562	3.1514151	4.1620612	1.2738574	3.6268926	2.2542357	3.6268926
1973	0.7569789	0.3439258	0.3135818	0.0998296	0.291045	0.1507218	0.291045
1974	1.3888623	1.0190804	1.136702	0.303471	0.9217556	0.5218	0.9218
1975	0.9021199	0.3253559	0.7207378	0.0963322	0.6806231	0.3805	0.6806
1976	0.8563512	.	0.6537884	.	0.5099699	0.2712	0.5100
1977	0.1353979	0.1719779	0.0723569	0.045225	0.067729	0.0378	0.0677
1978	0.9628702	0.62599	0.9071534	0.1935305	0.8488379	0.4987	0.8488
1979	1.9955728	1.3756718	1.5337195	0.5427137	1.4292399	0.8355	1.4292
1980	0.5952969	0.5004081	0.2717245	0.1677821	0.2795937	0.1531	0.2796
1981	0.6613324	0.3337981	0.6210098	0.074765	0.5234541	0.2919	0.5235
1982	0.4059054	0.1335774	0.3138193	0.0292986	0.2550768	0.1356	0.2551
1983	.	.	.	.	.	.	.
1984	2.0405179	1.4880547	1.7501975	0.444504	1.3948353	0.8067	1.3948
1985	0.9585819	0.6688764	0.7377141	0.2550966	0.6686145	0.3929	0.6686
1986	0.7388919	0.4106199	0.5132104	0.1431891	0.4206754	0.2319	0.4207
1987	1.7930828	1.2781103	1.4826175	0.5169287	1.2895715	0.7838	1.2896
1988	1.4754548	0.9346971	1.1240747	0.3792278	0.9153956	0.5571	0.9154
1989	2.9797256	2.2781083	2.5993815	1.0835528	2.418659	1.5495	2.4187
1990	1.9551152	1.5214748	1.7354485	0.6748743	1.4938539	0.9635	1.4939
1991	2.2962935	1.6971277	1.9424311	0.7819989	1.7561191	1.1138	1.7561
1992	0.9416075	0.6600262	0.7186298	0.2398406	0.6996238	0.4292	0.6996
1993	2.2348326	1.8273153	1.9410393	0.6377399	1.8425466	1.2341	1.8425
1994	2.3473261	1.8622409	2.0686132	0.7945529	2.1849083	1.4104	2.1849
1995	2.5334849	2.1562216	2.3321461	0.9732073	2.2820112	1.5013	2.2820
1996	1.1071121	0.8851425	0.99882	0.3489862	0.9041971	0.5667	0.9042
1997	1.1966707	0.9251818	1.0485204	0.4003691	0.9599347	0.6172	0.9599
1998	1.7785129	1.0489518	1.188208	0.5300623	0.9755818	0.6165	0.6344
1999	1.5683695	1.1138749	1.2779794	0.5079843	1.094434	0.6962	0.6962
2000	1.3337953	1.0148369	1.1561441	0.4729262	1.0054953	0.6542	0.6542
2001	2.1562252	1.6603006	1.8996524	0.6153995	0.8357822	0.5107	0.5107
2002	1.1715028	0.8340965	0.9696345	0.3365335	0.5075588	0.3097	0.3097
2003	3.0962514	2.2794888	2.574996	0.6116155	0.8405578	0.5323	0.5323
2004	2.6104159	2.1129926	2.40505	1.6236107	2.6579228	1.8387299	1.8387299
2005	0.5987844	0.4797654	0.5388234	1.0272511	1.9868246	1.3332931	1.3332931
2006	0.9634919	0.7843492	0.8892809	0.3815849	0.7670035	0.5107361	0.5107361

Table 3. Comparison of king bycatch estimates from the model 5 including BRD effects since 1997. Model All BRD data included experimental evaluations of 1994-1998 BRDs, Modern BRD excluded the 1994-98 BRD experiments data, and used only estimation of BRD effects based on 2000 forward observer data.

	All BRD data		Modern BRD only		Avg Nets VOUF Modern BRD	
year	Delta 5A	GLM 5A	Delta 5A	GLM 5A	Delta 5A	GLM 5A
1972	3.626893	0.705842	3.640285	0.71387	3.403666	0.667468
1973	0.291045	0.247241	0.289829	0.253242	0.272439	0.238047
1974	0.921756	0.270067	0.929158	0.277292	0.868763	0.259268
1975	0.680623	0.233509	0.68177	0.238927	0.640864	0.224592
1976	0.50997	0.261705	0.515664	0.267905	0.502772	0.261208
1977	0.067729	0.259631	0.067461	0.265485	0.072183	0.284069
1978	0.848838	0.497721	0.848286	0.507268	0.958563	0.573213
1979	1.42924	0.500383	1.434508	0.509158	1.699892	0.603352
1980	0.279594	0.349756	0.278472	0.35677	0.339736	0.43526
1981	0.523454	0.348856	0.52274	0.356108	0.645584	0.439794
1982	0.255077	0.323607	0.25601	0.331288	0.318733	0.412454
1983		0.302353	.	0.310101		0.381424
1984	1.394835	0.461273	1.390435	0.470246	1.689378	0.571349
1985	0.668615	0.438211	0.670273	0.446584	0.811031	0.540366
1986	0.420675	0.302963	0.422798	0.311207	0.511586	0.376561
1987	1.289571	0.702523	1.281452	0.712826	1.608222	0.894597
1988	0.915396	0.496395	0.918467	0.504022	1.157269	0.635067
1989	2.418659	1.213507	2.401291	1.222067	3.061646	1.558136
1990	1.493854	0.798454	1.495041	0.807398	1.951029	1.053655
1991	1.756119	0.996273	1.749059	1.005278	2.422447	1.39231
1992	0.699624	0.495614	0.70117	0.501309	0.936061	0.669248
1993	1.842547	1.021193	2.048668	1.093016	2.734972	1.459176
1994	2.184908	0.936745	2.272372	0.95491	3.033617	1.274806
1995	2.282011	1.039193	2.325437	1.08332	3.313748	1.543731
1996	0.904197	0.54453	0.91318	0.554116	1.351507	0.820091
1997	0.959935	0.690749	0.963524	0.697331	1.421198	1.028563
1998	0.63441	0.591602	0.817401	0.655095	1.16071	0.930235
1999	0.696237	0.53072	0.836729	0.586793	1.242543	0.871388
2000	0.654212	0.663543	0.774685	0.720777	1.158154	1.077562
2001	0.510689	0.535527	0.581021	0.567341	0.868626	0.848174
2002	0.309672	0.510337	0.347559	0.541082	0.538717	0.838676
2003	0.532305	0.546907	0.604672	0.576742	0.937242	0.89395
2004	1.83873	0.975943	2.007213	1.003087	3.11118	1.554785
2005	1.333293	0.607286	1.469356	0.626742	2.277501	0.97145
2006	0.510736	0.42326	0.595672	0.444788	0.923292	0.689421

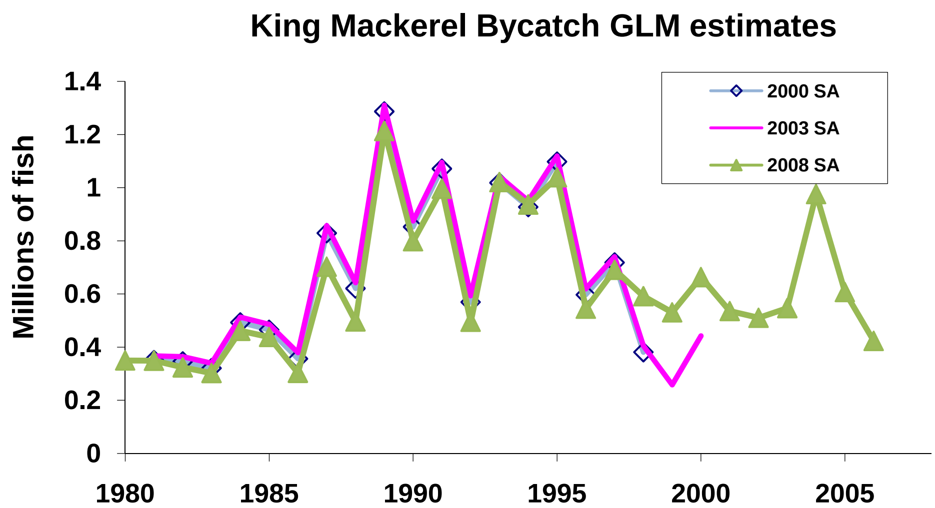
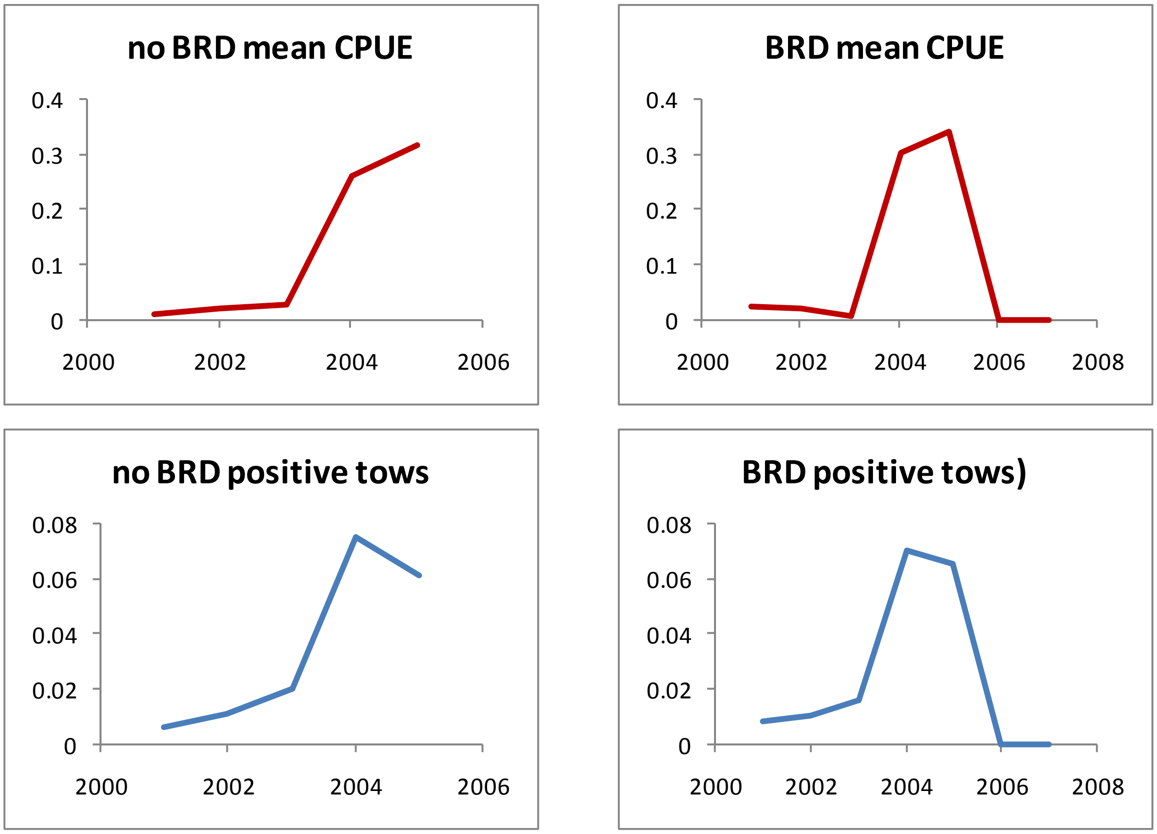


Figure 1. Comparison of GOM king mackerel bycatch estimates from 2000, 2003 and 2008 stock assessments. All estimates are from the GLM model 5 Actual, which included BRD effects since 1997.

Figure 2. Comparison of bycatch estimates for Gulf king mackerel from the six models by the GLM (open square marker line) and Delta lognormal (solid diamond marker line) approaches. (See text for details of model formulations and what data was included in each case). Units are millions of fish.



YEAR	N Obs	Nom CPUE king	% positive tows
2001	480	0.012032	0.006263
2002	1533	0.023633	0.011089
2003	802	0.030901	0.019975
2004	1057	0.262575	0.074882
2005	449	0.316745	0.060674

YEAR	N Obs	Nom CPUE king	% positive tows
2001	606	0.024169	0.008251
2002	1930	0.022659	0.010363
2003	795	0.006963	0.016373
2004	1080	0.304528	0.070501
2005	459	0.342051	0.065789
2006	32	0	0

Figure 3. Nominal estimates of catch rate (CPUE) (top row) and proportion of positive tows (bottom row) for king mackerel from the modern BRD and non-BRD observer data.

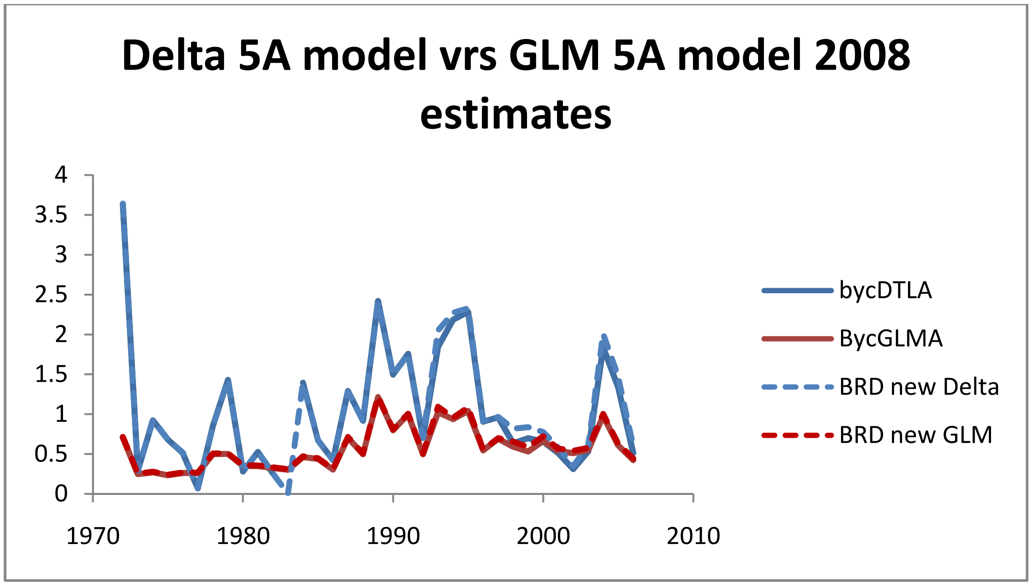


Figure 4. Comparison of Gulf king mackerel bycatch estimates for the Actual situation, including the effects of BRD use in the commercial shrimp fleet. Solid lines show the estimates of the GLM and delta model when all BRD observations are included, the broken lines show the estimates when only modern (post 2000) BRD data is included. Units are millions of fish.

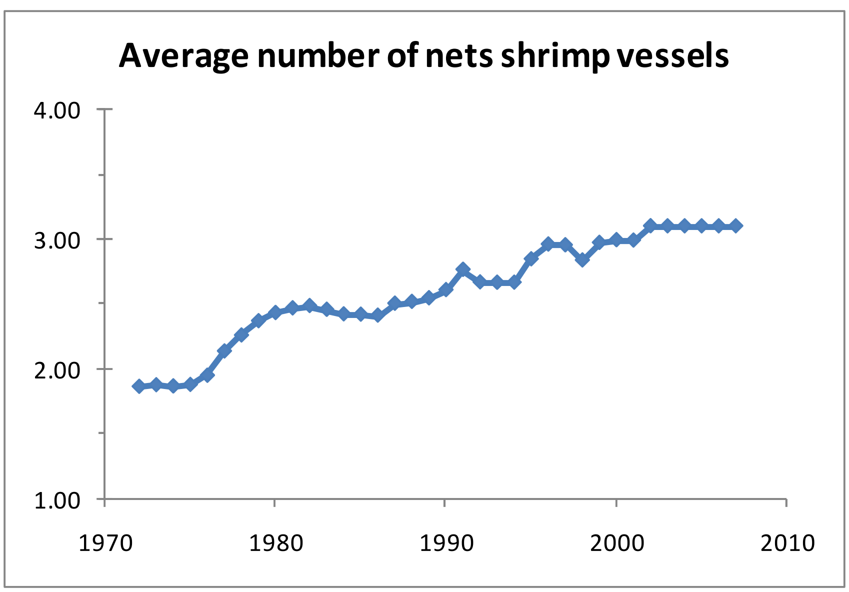


Figure 5. Average number of nets for a shrimp commercial vessel estimated from the VOUF files 1972-2006.

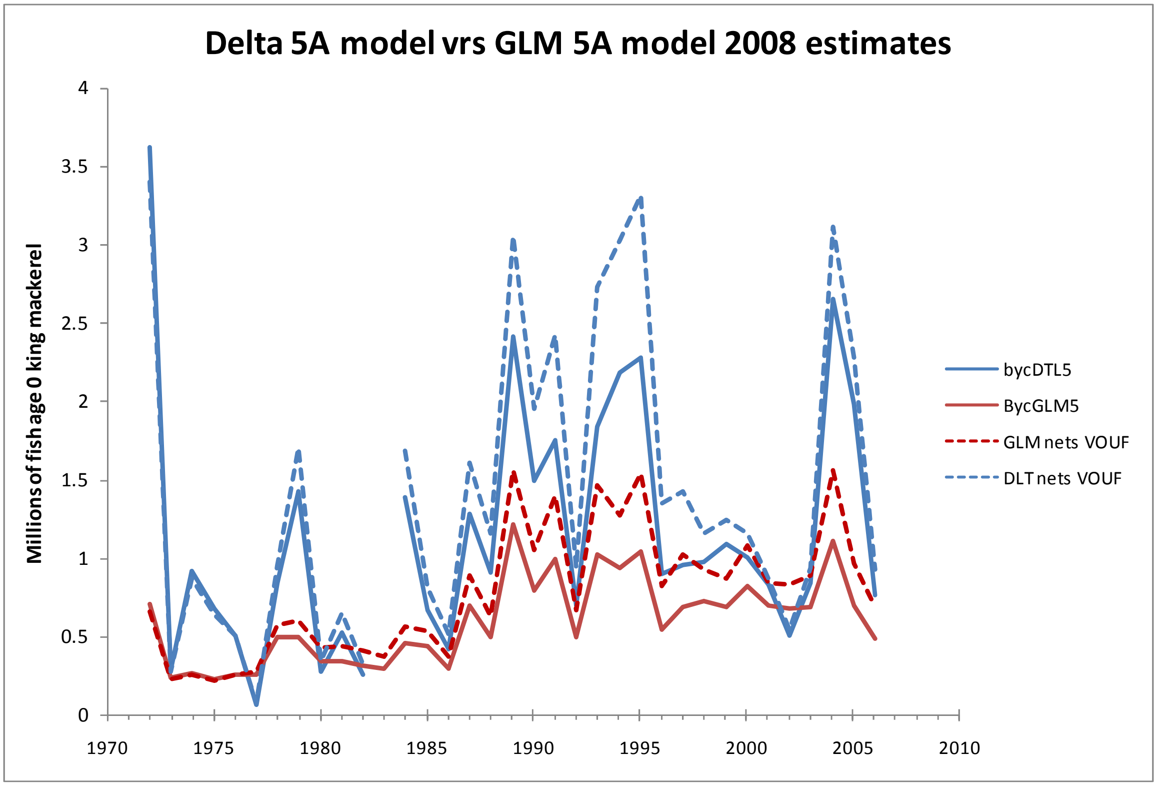


Figure 6. Estimates of king bycatch from the GOM shrimp fishery 1972-2006. Solid lines represent the estimates by the GLM and Delta models assuming 2 nets per commercial vessel for the whole time series, broken lines use an average number of nets estimated from the VOUF files. Estimates are from the model 5A which assumes BRD implementation after 1997 and use the BRD observations from the modern time series (post 2000).