South Atlantic Shrimp fishery bycatch of king mackerel

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South Atlantic shrimp fishery bycatch estimates of king mackerel

John Walter[1] and Jeff Isely[1]

Summary

To estimate shrimp bycatch of king mackerel in the South Atlantic a generalized linear modeling approach using a combination of observer data and SEAMAP scientific sampling similar to methods applied in the Gulf of Mexico was developed. Model factors were year, area, depth, season and survey type which accounted for the higher catch rate in the SEAMAP survey. Combining the two datasets provided spatial and temporal coverage with the SEAMAP dataset providing much of the annual trend and the OBSERVER dataset providing scaling to the fishery. Predictions were obtained by year, area, season, depth zone and grid. The strata-specific estimates of cpue were multiplied by effort on the same grid to estimate total bycatch. As estimates were derived for observer data collected after the mandatory implementation of bycatch reduction devices (BRDs) in 1999, estimates were adjusted to account for an estimated 27% reduction in discard catch rates. The effect of BRDs was obtained from the Gulf of Mexico where paired BRD and non-BRD experiments allowed for estimation of the reduction in catch rates of juvenile king mackerel. Estimates of shrimp fishery discards for the fishing years 1989-2012 range from 8,000-646,000 age-0 king mackerel with a median value of 100,000.

Introduction

Bycatch of non-target species in shrimp fisheries and its quantification is a critical input to many stock assessments. Most bycatch estimation methods use some type of statistical model to predict bycatch rate per unit effort on appropriate spatial and temporal scales, and then multiply this rate by the amount of effort, summing values to obtain total annual bycatch. The modeling of bycatch rate usually requires accounting for factors that influence catch rates such as season, depth, presence and use of bycatch reduction devices and other modifications. Furthermore, it often has involved combining multiple data sources ranging from design-based scientific surveys, fishery experiments and normal fishing operations recorded by onboard observers.

Shrimp bycatch estimates are needed for both assessment models used in SEDAR 38. For the VPA bycatch estimates are directly input into the catch at age matrix, assuming that all bycatch is of age-0 and that all are dead. For Stock Synthesis (SS), shrimp bycatch was modeled using the Stock Synthesis “super-year” approach, where instead of using annual estimates of bycatch, the model uses a median of the time series and estimates bycatch fishing mortality using a time series of shrimp effort. As shrimp effort is considered more precisely known, this has become the preferred method of incorporating bycatch information into SS assessments. Nonetheless, this method requires a median value of bycatch over the modeled time series.

In this paper we quantify bycatch of king mackerel in the South Atlantic using methods similar to those employed in the Gulf of Mexico. We use a two-stage or delta generalized linear model to predict bycatch rate using a combination of observer data and SEAMAP survey information. We then obtain annual bycatch estimates by summing the product of BCPUE and effort in hours towed. We also develop a time series of historical shrimp effort needed for assessment models.

Methods

Datasets

Several datasets were used to estimate shrimp bycatch CPUE. The primary dataset was Southeast observer program data obtained by onboard observers on shrimp boats (Table 1). These data consist of many different datasets from a diversity of experiments and standard fishery observation. For the South Atlantic, most of the data from commercial vessels come from the observer programs initiated in 2001 (Table 2). There are very sparse numbers of tows without bycatch reduction devices, so no estimation of its effect within the South Atlantic models was possible however, for the Gulf of Mexico, there was substantial overlap in the use/non-use of BRDs so its effect could be estimated and applied to the Atlantic (see below). Many tows were from the rock shrimp fishery which operates deeper than 30m and for which catch rates of king mackerel were extremely low, but not zero (Table 2, Figure 1). Fishery type (dataset) and depth were included as model factors to account for the differences in catch rates. Commercial catch rates were adjusted to a per-net-hour basis by dividing the total catch (reported for all nets used) by the number of hours fished and the total number of nets.

The second primary dataset was the South Atlantic SEAMAP trawl survey (Smart and Boylan 2013), a fishery-independent stratified random survey that uses a mongoose, high opening net, no BRDs and a 20 minute tow. Catch rates were adjusted to a per net hour basis by multiplying the reported catch (per two nets, per 20 minutes) by 3 and dividing by two. The SEAMAP trawl survey conducts about 300 tows per year since 1989.

Overall catch rates in the SEAMAP trawl survey were about 3.4 fish per net hour with 21% positive tows (Table 2). For the observer dataset, the average catch rates were about 0.48 fish per net hour with a 6% positive rate. The spatial coverage of the SEAMAP survey was relatively extensive and overlapped the fishery. Based on the observed shrimp effort and with the exception of the offshore rock shrimp fishery, most all of the effort is confined to a narrow area along the coast in waters less than 10 meters (Figure 1). Observed shrimp tows had relatively sparse spatial and temporal coverage such that most of the spatial and annual signals are driven by the SEAMAP survey.

As some of the dataset codes were difficult to find, they have been included in this document as appendix 1 and 2, for future reference.

Modeling

Model factors included year (YR), area (AR), depth (DP), season (SEAS) and dataset (DSET). The modeled years were three depth zones were modeled; 0-10 meters, 10-30 meters and 30+ meters. Spatial structure was at the state level; FL, GA, SC and NC. Three seasons were modeled and three datasets were used: B (Commercial BRD tows), SEAMAP_ATL, and rock shrimp. The initial (and also, after model selection, final) models tested are shown below:

LogisticGLM=glm(POS ~ (YR + AR + DP + SEAS + DSET)-1 , family =binomial(link = "logit") , data=SAKM , offset = HRSFISHD)

CPUE_GLM =glm(log(CPUE9)~ (YR + AR + DP + SEAS + DSET)-1 , family = gaussian(link = "identity"),data = SAKMPOS)

Stepwise deletion of model factors was performed to select models with the final model chosen on the basis of the lowest AIC. For the logistic model all model factors were significant. For the lognormal submodel, depth zone was not significant but was retained in the final model to be consistent with the logistic submodel to that predictions on the same prediction grid could be obtained. For the logistic glm model an offset of hours fished was used in the models and the predictions were obtained with an offset value of 1 hour fished. Data estimated on the lognormal scale was back-transformed with a bias correction function of Lo et al. (1992). The final catch per unit effort prediction was obtained as the product of the lognormal and logistic model components. The variance of this product was obtained by using the Goodman (1960) exact formula for the product of two independent random variables.

Models with a Gaussian and Gamma distributional families with a log link were explored but due to poor diagnostic performance were not used.

All annual bycatch and effort estimates are reported or estimated in South Atlantic fishing year definitions (April 1-March 30).

Shrimp effort estimation

Shrimp effort data come from several sources: state trip ticket data from for FL from 1986-present, NC from 1994 to the present, SC from 2004 to the present, and GA from 2001 to the present (SEDAR38-RW-03). Data for years from 1978 to the period covered by trip tickets are available from the South Atlantic Shrimp (SAS) database at the SEFSC. The SAS system covers 1978-1991 for NC, 1978-2000 for GA, 1978-2003 for SC and 1981-1992 for FL (Table 3). In the shrimp effort dataset there are multiple gear types, but most effort is of some type of pulled trawl net. Effort was summed for three gear categories: “OTTER TRAWL BOTTOM, SHRIMP", "SHRIMP TRAWL", "OTTER TRAWLS”.

As shrimp effort was in number of trips but the shrimp bycatch rates were in number per hour towed, it was necessary to obtain the average number of tows per trip and the average number of hours per tow obtained from (SEDAR28-AW02) and originally came from state trip ticket data.

Shrimp effort was not identified to depth zone or between rock shrimp and other inshore shrimp types. As bycatch rates were different by depth and between rock shrimp and other shrimp tows it was necessary allocate the effort data proportionally by depth and target. The depth allocation of effort was obtained from the allocation of depths fished in the observed trips; roughly 98% in 0-10 meters, 1.5% in 10-30 meters and 0.07% in 30^+ meters. This makes two strong assumptions: a) that the depth distribution of observed tows is representative of the entire fleet, and b) that the depth distribution of shrimp fishing in the South Atlantic has been constant over time. Given the dominance of effort in the 0-10 meter zone, these assumptions are likely reasonable.

Then, as all rock shrimp effort was obtained in 30^+ meters, some fraction of the 0.07% of effort in this depth zone had to be allocated to rock shrimp. This was obtained from the proportion of the annual rock shrimp landings to total shrimp landings (generally ~0.8%). This makes the assumption that effort for the shrimp species is proportional to landings. Then this fraction was used to partition the remaining fraction of effort in the 30^+ m depth zone. In general these decisions were relatively inconsequential for king mackerel bycatch as catch rates were estimated to be low in the 30^+m depth zone; however, this exercise of properly partitioning effort to depth zone and target species was influential in Gulf of Mexico bycatch estimates for other species so it is an important consideration.

For modeling the shrimp fishery in Stock Synthesis a time series of historical shrimp effort was developed (Figure 2). The shrimp fishery was assumed to start in 1929 (0 in 1928) and a linear ramp from 1928 to 1944 with the same slope as the 1929-1945 time period. The 1945 estimate of 4400 trips was obtained from using a slow, steady increase of about 250 trips per year starting in 1929. From 1945 onwards a faster increase (1060 trips/year) was invoked that had a slope similar to the increase in shrimp boat building at the DESCO boat yard in St. Augustine FL, one of the largest shrimp boat builders (http://www.staugustinelighthouse.org/LAMP/ Heritage_Boatbuilding). Then in 1955, a faster rate of increase (1500 trips/year) was invoked that reflected an increase in the rate of boat building. This increase was allowed up until 1962. Then for the years 1963-1977 the average of the first 3 years of modern data collection (1978-1980) was used for all years to reflect a well-developed fishery. These increases tend to reflect the increasing in shrimp landings, particularly the buildup of the shrimp fishery in South Carolina and the fact that it was well-developed by the late 1950s and relatively during the 1960-70s. (http://www.nerrs.noaa.gov/doc/siteprofile/acebasin/html/ resource/commfish/cfshmpfh.htm.

Accounting for the effect of bycatch reduction devices

As the bycatch estimates obtained for the South Atlantic used observer data post-BRD implementation, they do not estimate bycatch for the time period prior to 1999. To account for the higher bycatch rates that would have been likely pre-BRDs we used an estimate of the effect of BRDs from the Gulf of Mexico to apply to the South Atlantic starting for all years prior to 1999. The estimate of BRD effect was obtained from the datasets used to estimate Gulf king mackerel bycatch where there were both BRD/NonBRD tows. For the South Atlantic, all observed shrimp tows had BRDs in place. The BRD effect was estimated by obtaining a commercial BRD and commercial Non-BRD catch rates and estimating the percentage difference between the two, from the Gulf observer data, using the overall GLM model developed to estimated Gulf bycatch. The BRD effect was then used to adjust the bycatch rates back in time to account for the reduction in bycatch associated with BRDs after 1999. The estimated effect was of a 27% reduction in king mackerel bycatch with BRDs, so estimates prior to 1999 were increased by a factor of 1.37= (1/(1-0.27)).

Results and discussion

Model fits

Overall the model fit reasonably well though there was some lack of fit to a normal distribution for the log(CPUE of positives) (Figure 3). Plots of the residuals versus the fitted values displayed patterns indicative of a discrete distribution, rather than a continuous distribution as often only 1, 2 or 3 fish were observed. Future modeling may want to consider a poissson or negative binomial distribution for these discrete observations.

Estimated bycatch

Estimated bycatch of age-0 king mackerel ranges from 8,000-646,000 age-0 king mackerel. Coefficients of variation on these estimates are low (~0.13), however as the interannual variability is largely determined by the SEAMAP survey, there is not high confidence in the interannual estimates. The absolute magnitude of bycatch has dropped in recent years, corresponding to decreases in fishing effort and decreases in catch rates in the SEAMAP index.

The estimated catch rates for the SEAMAP dataset are much higher than those for commercial shrimping, even if the 27% effect of BRDs is considered. It is not known exactly why these differences exist; however, they could be due to finer scale depth stratification than used in this modeling, the fact that the fishery actively targets high catch rates of shrimp, rather than sampling randomly or gear configuration differences between the fishery and the survey
This pattern of higher research survey catch rates than commercial is also evident in the Gulf of Mexico. When compared with catch rates from the Gulf of Mexico commercial estimates on a per net hour basis, the estimates for the South Atlantic are very similar in magnitude (Figure 5) indicating that the commercial shrimp fishery in both basins has similar bycatch rates. The absolute magnitude differs due to the higher number of trips in the Gulf of Mexico.

Overall these estimates are higher than values used in SEDAR 16. The methodology used in SEDAR 38 represents an improvement in that it incorporates observer data from commercial shrimp trawling to estimate the magnitude of bycatch rate, incorporates a BRD effect and more accurately reflects spatial and temporal distribution of bycatch rate and shrimp effort. Further, this methodology is now very similar to methods used estimate king mackerel bycatch in the Gulf of Mexico.

The approach used here also differs from that used in SEDAR28AW02 primarily in that the SEAMAP trawl survey data was used to augment the sparse spatial and temporal coverage of the observer data. The SEAMAP datasets provided most of the spatial and temporal trends, while the overlap between the SEAMAP and the observer data provided the critical scaling factor that differentiated research survey data from commercial fishing practices.

Future improvements in estimating bycatch in the shrimp fishery could involve more accurately defining the spatial and seasonal distribution of shrimp fishing effort and determining why there is a much higher catch rate of king mackerel in the SEAMAP trawl survey than in commercial shrimp trawls. Further refinements in the historical time series of shrimp effort could also improve the use of this series in other assessment models.

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Table 1. Datasets used in the estimation of shrimp bycatch for the Gulf and South Atlantic (blue)

set	BRD	USE	Gulf SA	DSET	Name/Description
1	NO	yes	Gulf	RG	CPUES.OREGON1 *SEAMAP Gulf trawl survey
2	NO	yes	SA	SEAMAP	CPUES.SEAMAP_ATL * SEAMAP atlantic trawl survey
3	NO	yes	Gulf	C	CPUES.OLDOBS1 old obs data, assume no BRDs or TEDs, YR >= 1972 & YR <= 1985 old obs;
4	yes	yes	Gulf/SA	C	CPUES.RRPCHAR1 historical observer data, 1992-1997 characterization of all spec
5	yes	yes	Gulf/SA	B	CPUES.RRPEVAL1 *historical observer data, 1992-1997 paired with BRDS;
6	NO	NO	Gulf/SA	DNU	CPUES.RRPONLY1 *historical observer data, 1992-1997 snapper/shrimp only;
7	yes	yes	Gulf/SA	B	CPUES.RRPBRDS1 *historical observer data, 1992-1997 with BRD paired with EVAL
8	yes	NO	Gulf/SA	DNU	CPUES.RRPBNLY1 *historical observer data, 1992-1997 with BRD snapper/shrimp only;
9	NO	yes	Gulf	B	CPUES.FDEVAL1 *BRD study, paired with BRDS, 1998 ;
10	yes	yes	Gulf	C	CPUES.FDBRDS1 *BRD study, paired with EVAL , 1998 ;
11	yes	NO	Gulf	DNU	CPUES.FDBNLY1 *BRD study, with BRD snapper/shrimp only, 1998 ;
12	NO	NO	Gulf	DNU	CPUES.FDONLY1 *BRD study, ctrl side snapper/shrimp only, 1998 ;
13	NO	NO	Gulf	DNU	CPUES.MOACO1 SIXTH SET
14	NO	NO	Gulf	DNU	CPUES.MOAEO1 FIFTH SET A PROJECT EXPTL SIDE NO BRDS SNAPPER ONLY;
15	yes	yes	Gulf/SA	B	CPUES.MOAEB1 MODERN OBSERVER THIRD SET A PROJECTS EXPTL SIDE (WITH BRD)
16	NO	yes	Gulf/SA	B	CPUES.MOACN1 MODERN OBSERVER THIRD SET A PROJECTS CTRL SIDE (WITH BRD)
17	NO	NO	Gulf	DNU	CPUES.MOECB1 EFFORT PROJECT CONTROL DESIGNATION (HAVE BRDS) SNAPPER ONLY;
18	yes	NO	Gulf	DNU	*CPUES.MOEEB1 EFFORT PROJECT EXPTL DESIGNATION W/ BRDS SNAPPER ONLY;
				C	commercial observer
				B	commercial BRD
				SEAMAP	Research Vessel Atlantic
				RG	Research Vessel Gulf
				DNU	Do not use

Table 2.

	Tows				Percentage positive				CPUE			
year	BRD	no BRD	Rock shrimp	SEAMAP ATL	BRD	no BRD	Rock shrimp	SEAMAP ATL	BRD	no BRD	Rock shrimp	SEAMAP ATL
1989	-	-	-	265	-	-	-	23%	-	-	-	1.68
1990	-	-	-	274	-	-	-	39%	-	-	-	6.37
1991	-	-	-	269	-	-	-	21%	-	-	-	1.18
1992	-	-	-	277	-	-	-	17%	-	-	-	4.92
1993	-	-	-	277	-	-	-	17%	-	-	-	1.53
1994	-	-	-	277	-	-	-	19%	-	-	-	1.92
1995	-	-	-	277	-	-	-	26%	-	-	-	4.92
1996	-	-	-	277	-	-	-	35%	-	-	-	7.51
1997	-	-	-	277	-	-	-	19%	-	-	-	1.48
1998	-	-	-	276	-	-	-	25%	-	-	-	7.10
1999	-	-	-	277	-	-	-	30%	-	-	-	2.06
2000	-	-	-	277	-	-	-	21%	-	-	-	2.82
2001	30	12	15	306	13%	0%	0%	17%	0.53	0.00	0.00	2.37
2002	13	-	108	306	0%	-	1%	21%	0.00	-	0.01	1.43
2003	2	6	181	306	0%	0%	6%	25%	0.00	0.00	0.18	3.35
2004	-	-	-	306	-	-	-	24%	-	-	-	7.96
2005	159	-	-	306	23%	-	-	19%	2.82	-	-	5.44
2006	-	-	22	306	-	-	0%	20%	-	-	0.00	3.66
2007	138	-	-	306	14%	-	-	23%	0.77	-	-	3.65
2008	309	-	122	306	2%	-	0%	16%	0.14	-	0.00	5.18
2009	667	-	20	336	6%	-	0%	17%	0.47	-	0.00	2.04
2010	215	-	57	335	0%	-	2%	13%	0.00	-	0.11	0.94
2011	426	-	-	336	1%	-	-	12%	0.06	-	-	2.65
2012	558	2	-	336	0%	0%	-	14%	0.01	0.00	-	1.61
Totals / averages	2517	20	525	7091	6%	0%	1%	21%	0.48	0.00	0.04	3.49

Table 2. Effort estimates in number of trips. Values in yellow were averages for two adjacent years.

Fishing Year	FL	GA	NC	SC	Grand Total
1978		10710	13313.5		24023.5
1979		14646	16456.7	11290	42392.7
1980		13161	32683.7	14646	60490.7
1981	4898	6719	24446.5	8880	44943.5
1982	5217	11249	37941.6	13779.3	68186.9
1983	5203.3	12312	36546.4	10612.8	64674.5
1984	4810	5683.1	27289.4	5627	43409.5
1985	5163.1	7523.2	24165	5452.2	42303.5
1986	4332.2	10025	24175.9	9882.1	48415.2
1987	4212.9	9245	19307	11438	44202.9
1988	4967.9	9150.4	24913.1	8387.5	47418.9
1989	5124.4	7711	30076.9	10192	53104.3
1990	6246	6247	19558.4	9634.6	41686
1991	5843	10131	24790.1	13827	54591.1
1992	4757	8927	9490.8	12386	35560.8
1993	5347	8977	Avg 92-94	11620	25944
1994	6500	8577	16517	10156	41750
1995	5764	9886	16884	12175	44709
1996	5629	7771	11569	9136	34105
1997	5332	8935	13582	11280	39129
1998	5163	7931	9486	9485	32065
1999	5107	7194	13716	10006	36023
2000	3678	5292	12918	9514	31402
2001	3225	3110	9823	6249	22407
2002	2876	3745	12431	7074	26126
2003	2770	3461	9003	6293	21527
2004	2752	2751	6202	5954	17659
2005	2656	2434	4331	4131	13552
2006	2500	2073	4237	3661	12471
2007	2312	1651	6672	3268	13903
2008	2152	1784	5979	3531	13446
2009	2175	1772	5746	3194	12887
2010	2665	2224	5515	4346	14750
2011	2758	1935	4357	3176	12226
2012	2595	1909	6179	4202	14885
2013	1365	1234		2006	4605

Table 3. Hours fished per trip. Values in blue were averages for the last three years.

Year	NC	SC	GA	FL
1978	18.32	14.84	28.04	18.45
1979	18.32	14.84	28.04	18.45
1980	18.32	14.84	28.04	18.45
1981	18.32	14.84	28.04	18.45
1982	18.32	14.84	28.04	18.45
1983	18.32	14.84	28.04	18.45
1984	18.32	14.84	28.04	18.45
1985	18.32	14.84	28.04	20.7
1986	18.32	14.84	28.04	16.81
1987	18.32	14.84	28.04	17.85
1988	18.32	14.84	28.04	17.89
1989	18.32	14.84	28.04	17.57
1990	18.32	14.84	28.04	18.48
1991	18.32	14.84	28.04	15.14
1992	18.32	14.84	28.04	16.1
1993	18.32	14.84	28.04	16.39
1994	18.32	14.84	28.04	15.69
1995	18.32	14.84	28.04	14.87
1996	18.32	14.84	28.04	13.67
1997	18.32	14.84	28.04	12.4
1998	18.32	14.84	28.04	14.48
1999	18.32	14.84	28.04	13.61
2000	18.03	14.84	28.04	13.34
2001	17.7	14.84	28.04	14.07
2002	19.21	14.84	28.1	14.46
2003	15.56	14.11	28.36	20.48
2004	19.72	17.71	27.66	19.98
2005	16.14	12.71	24.27	19.13
2006	16.46	12.1	24.38	17.27
2007	17.57	10.69	23.83	16.53
2008	21.18	10.01	22.13	15.41
2009	17.79	11.33	23.74	15.34
2010	17.05	11.06	21.78	15.82
2011	*18.67*	*10.80*	*22.55*	*15.52*
2012	*18.67*	*10.80*	*22.55*	*15.52*

Table 4. Number of nets per tow. Values in blue were averages for the last three years.

Year	NC	SC	GA	FL
1978	2.24	2.6	2.99	1.64
1979	2.24	2.6	2.99	1.64
1980	2.24	2.6	2.99	1.64
1981	2.24	2.6	2.99	1.64
1982	2.24	2.6	2.99	1.64
1983	2.24	2.6	2.99	1.64
1984	2.24	2.6	2.99	1.64
1985	2.24	2.6	2.99	1.64
1986	2.24	2.6	2.99	1.64
1987	2.24	2.6	2.99	1.64
1988	2.24	2.6	2.99	1.64
1989	2.24	2.6	2.99	1.64
1990	2.24	2.6	2.99	1.64
1991	2.24	2.6	2.99	1.67
1992	2.24	2.6	2.99	1.66
1993	2.24	2.6	2.99	1.6
1994	2.24	2.6	2.99	1.65
1995	2.24	2.6	2.99	1.64
1996	2.24	2.6	2.99	1.88
1997	2.24	2.6	2.99	1.81
1998	2.24	2.6	2.99	1.53
1999	2.24	2.6	2.99	1.48
2000	2.1	2.6	2.99	1.42
2001	2.29	2.6	2.99	1.6
2002	2.32	2.6	3.02	1.64
2003	2.33	2.55	2.98	1.89
2004	2.39	2.58	2.98	1.83
2005	2.25	2.66	2.93	1.87
2006	2.47	2.61	3.09	2.03
2007	2.48	2.6	3.17	2.15
2008	2.58	2.61	2.93	1.96
2009	2.44	2.58	3.05	1.88
2010	2.4	2.55	2.92	2.03
2011	*2.47*	*2.58*	*2.97*	*1.96*
2012	*2.47*	*2.58*	*2.97*	*1.96*

Table 5. Binomial model

Call: glm(formula = POS ~ (YR + AR + DP + SEAS + DSET) - 1, family = binomial(link = "logit"),
data = SAKM, offset = HRSFISHD)

Coefficients:

```
            Estimate Std. Error z value Pr(>|z|)
YR1989       -6.43689   0.24490 -26.284  < 2e-16 ***
YR1990       -5.70487   0.22698 -25.134  < 2e-16 ***
YR1991       -6.79432   0.24219 -28.053  < 2e-16 ***
YR1992       -7.02576   0.24793 -28.338  < 2e-16 ***
YR1993       -7.11532   0.24986 -28.477  < 2e-16 ***
YR1994       -6.86880   0.24456 -28.087  < 2e-16 ***
YR1995       -6.45132   0.23491 -27.463  < 2e-16 ***
YR1996       -5.86911   0.22728 -25.824  < 2e-16 ***
YR1997       -6.82318   0.24360 -28.010  < 2e-16 ***
YR1998       -6.35096   0.23311 -27.244  < 2e-16 ***
YR1999       -6.09907   0.22918 -26.612  < 2e-16 ***
YR2000       -6.73558   0.24107 -27.940  < 2e-16 ***
YR2001       -7.28338   0.22739 -32.030  < 2e-16 ***
YR2002       -6.90867   0.22671 -30.473  < 2e-16 ***
YR2003       -6.52896   0.22285 -29.298  < 2e-16 ***
YR2004       -6.61239   0.22790 -29.015  < 2e-16 ***
YR2005       -6.38155   0.20461 -31.189  < 2e-16 ***
YR2006       -6.97932   0.23480 -29.724  < 2e-16 ***
YR2007       -6.50828   0.21283 -30.579  < 2e-16 ***
YR2008       -7.45170   0.21939 -33.966  < 2e-16 ***
YR2009       -7.20116   0.18344 -39.255  < 2e-16 ***
YR2010       -7.64156   0.23396 -32.661  < 2e-16 ***
YR2011       -7.75702   0.22821 -33.990  < 2e-16 ***
YR2012       -7.75865   0.21743 -35.683  < 2e-16 ***
AR6          -1.11698   0.09172 -12.178  < 2e-16 ***
AR7          -1.37418   0.08855 -15.519  < 2e-16 ***
AR8          -1.77438   0.11141 -15.927  < 2e-16 ***
DP2          -0.98948   0.13605  -7.273 3.51e-13 ***
DP3          -2.84541   1.08274  -2.628  0.00859 **
SEAS2         1.33416   0.12659  10.539  < 2e-16 ***
SEAS3         2.64023   0.12521  21.086  < 2e-16 ***
DSETRS       -2.36579   0.39957  -5.921 3.20e-09 ***
DSETSEAMAP_ATL  4.60260   0.12255  37.556  < 2e-16 ***
---
Signif. codes:  0 ‘***’ 0.001 ‘**’ 0.01 ‘*’ 0.05 ‘.’ 0.1 ‘ ’ 1

(Dispersion parameter for binomial family taken to be 1)
    Null deviance: 29074.6  on 10153  degrees of freedom
Residual deviance:  7068.1  on 10120  degrees of freedom
AIC: 7134.1
Number of Fisher Scoring iterations: 7
```

Table 6. Lognormal model

Call:

glm(formula = log(CPUE9) ~ (YR + AR + DP + SEAS + DSET) - 1,
family = gaussian(link = "identity"), data = SAKMPOS)

Coefficients:

	Estimate	Std. Error	t value	Pr(>|t|)	
YR1989	1.19559	0.26085	4.584	4.93e-06	***
YR1990	1.68262	0.23714	7.096	1.93e-12	***
YR1991	1.17675	0.26099	4.509	7.00e-06	***
YR1992	1.60222	0.26736	5.993	2.55e-09	***
YR1993	1.00927	0.26597	3.795	0.000153	***
YR1994	1.32814	0.26356	5.039	5.21e-07	***
YR1995	1.50728	0.24792	6.080	1.51e-09	***
YR1996	1.73893	0.23862	7.287	4.95e-13	***
YR1997	1.29717	0.24319	5.334	1.10e-07	***
YR1998	1.89453	0.24907	7.606	4.80e-14	***
YR1999	1.35691	0.23687	5.728	1.21e-08	***
YR2000	1.35790	0.25540	5.317	1.21e-07	***
YR2001	1.14511	0.24654	4.645	3.69e-06	***
YR2002	1.04282	0.24003	4.344	1.48e-05	***
YR2003	1.46384	0.24335	6.015	2.22e-09	***
YR2004	1.81539	0.23734	7.649	3.49e-14	***
YR2005	1.95306	0.21132	9.242	< 2e-16	***
YR2006	1.84941	0.24496	7.550	7.30e-14	***
YR2007	1.90155	0.22231	8.554	< 2e-16	***
YR2008	2.14401	0.24767	8.657	< 2e-16	***
YR2009	1.42171	0.20546	6.920	6.53e-12	***
YR2010	1.18198	0.26866	4.400	1.16e-05	***
YR2011	1.68775	0.25783	6.546	7.95e-11	***
YR2012	0.86329	0.25167	3.430	0.000618	***
AR6	-0.79601	0.08414	-9.461	< 2e-16	***
AR7	-0.80374	0.08064	-9.967	< 2e-16	***
AR8	-0.38706	0.10935	-3.540	0.000412	***
DP2	-0.03265	0.14101	-0.232	0.816913	
DP3	-0.92959	1.24863	-0.744	0.456690	
SEAS2	0.07164	0.14527	0.493	0.621969	
SEAS3	0.50849	0.14259	3.566	0.000373	***
DSETRS	-0.96351	0.40801	-2.361	0.018323	*
DSETSEAMAP_ATL	0.47841	0.13532	3.535	0.000419	***

Signif. codes: 0 ‘***’ 0.001 ‘**’ 0.01 ‘*’ 0.05 ‘.’ 0.1 ‘ ’ 1

(Dispersion parameter for gaussian family taken to be 1.395024)

Null deviance: 7563.1 on 1625 degrees of freedom

Residual deviance: 2220.9 on 1592 degrees of freedom

AIC: 5187.2

Number of Fisher Scoring iterations: 2

Table 7. Estimated bycatch of age-0 king mackerel in South Atlantic shrimp fishery. Values in blue are obtained by multiplying the average number per trip over the entire time series by the number of trips in each year.

Fishing YEAR	Trips	Bycatch Number	SE	CV	LCI	UCI	number per trip	27% change-BRD effect
1978	25817.5	*96930*					*3.75*	132781
1979	41844.7	*157104*					*3.75*	215210
1980	61144.7	*229564*					*3.75*	314472
1981	45808.5	*171985*					*3.75*	235596
1982	69700.6	*261687*					*3.75*	358475
1983	62568.9	*234911*					*3.75*	321796
1984	42984.4	*161382*					*3.75*	221072
1985	43974.6	*165100*					*3.75*	226165
1986	48628.1	*182571*					*3.75*	250098
1987	44023.9	*165285*					*3.75*	226418
1988	47646.3	*178885*					*3.75*	245048
1989	51014	130627	16899	0.129	110227	154801	2.56	178940
1990	45899	472210	60731	0.129	398859	559051	10.29	646863
1991	52544	87622	11334	0.129	73940	103837	1.67	120030
1992	34264	89582	13175	0.147	73873	108632	2.61	122716
1993	27535	43655	7065	0.162	35318	53960	1.59	59801
1994	55203	107087	13412	0.125	90850	126226	1.94	146695
1995	41603	168963	21313	0.126	143177	199393	4.06	231456
1996	35488	340409	42824	0.126	288584	401540	9.59	466313
1997	38718	86448	11577	0.134	72517	103056	2.23	118422
1998	33073	214661	27464	0.128	181475	253916	6.49	294057
1999	34758	156586	19130	0.122	133377	183833	4.51	156586
2000	30016	64596	8220	0.127	54658	76340	2.15	64596
2001	24315	26334	3328	0.126	22308	31087	1.08	26334
2002	24281	33342	3942	0.118	28546	38944	1.37	33342
2003	21479	81181	10534	0.130	68468	96254	3.78	81181
2004	17593	107182	14647	0.137	89590	128228	6.09	107182
2005	13709	124097	16374	0.132	104366	147557	9.05	124097
2006	12581	53171	8055	0.151	43597	64848	4.23	53171
2007	13797	91501	12018	0.131	77013	108714	6.63	91501
2008	13395	43322	6285	0.145	35818	52398	3.23	43322
2009	12642	23327	2479	0.106	20286	26823	1.85	23327
2010	14770	15279	2494	0.163	12339	18919	1.03	15279
2011	13236	19836	3130	0.158	16131	24391	1.50	19836
2012	14205	8036					0.57	8036

* 2012-13 estimates are not complete but use an average for the last three years for the missing months

Figure 1. Spatial plots of A. shrimp observer data and B. SEAMAP data with positive tows shown in green and C. overlap of SEAMAP (red) and Observer (black) data. Locations of observer data are jittered to and represent multiple years of data.

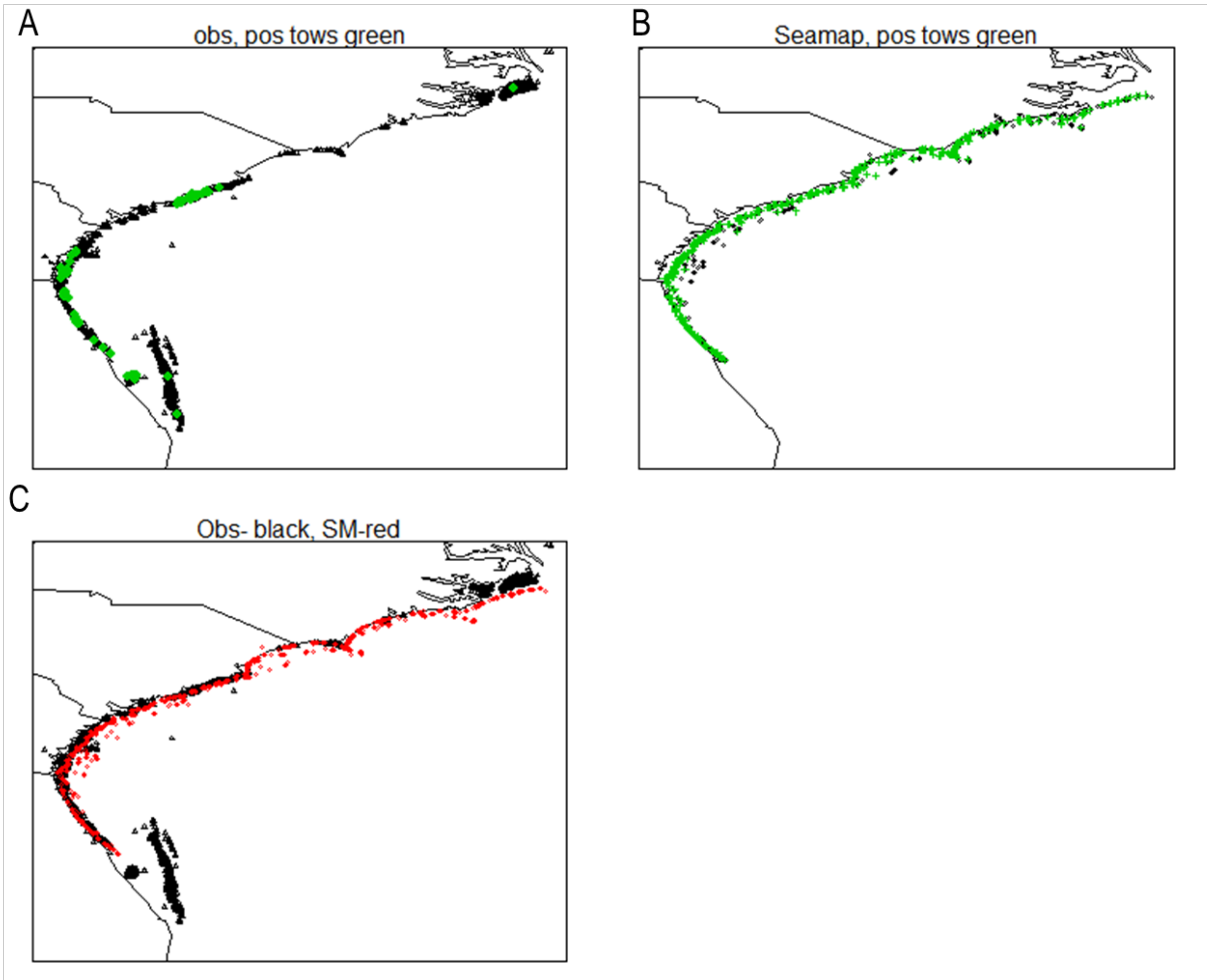


Figure 2. Time series of South Atlantic shrimp effort showing historical build up from 1925 and the substantial increases immediately after WWII commensurate with the boat building trends in the DESCO shipyard in St Augustine, FL. DESCO boat building trends come from: http://www.staugustinelighthouse.org/LAMP/Hertiage_Boatbuilding/

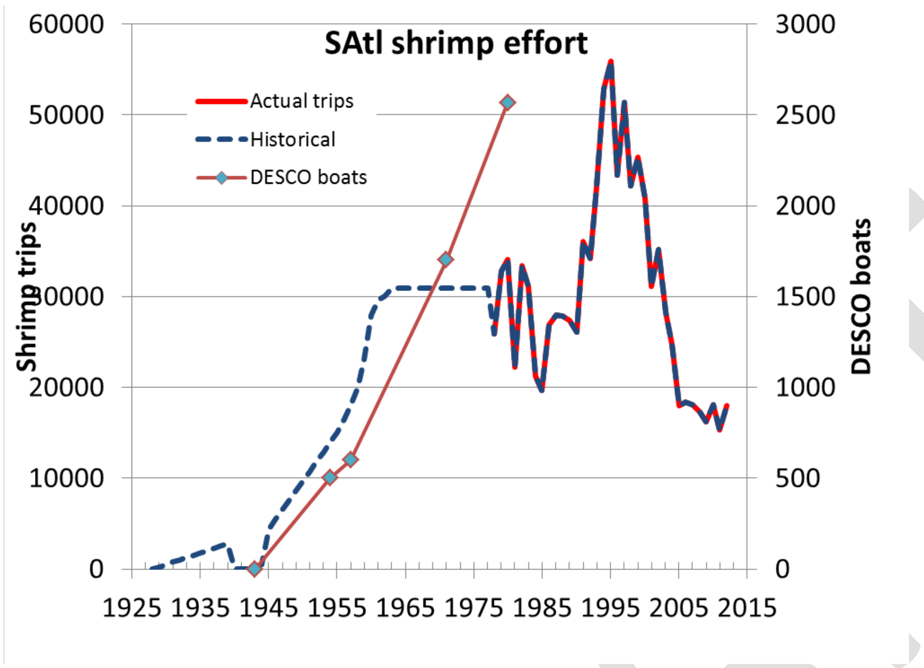


Figure 3. Plot of frequency distribution of positive CPUE, log of positive CPUE, residuals versus fitted values, normal q-q plots, scale versus location plots and leverage versus residual plot.

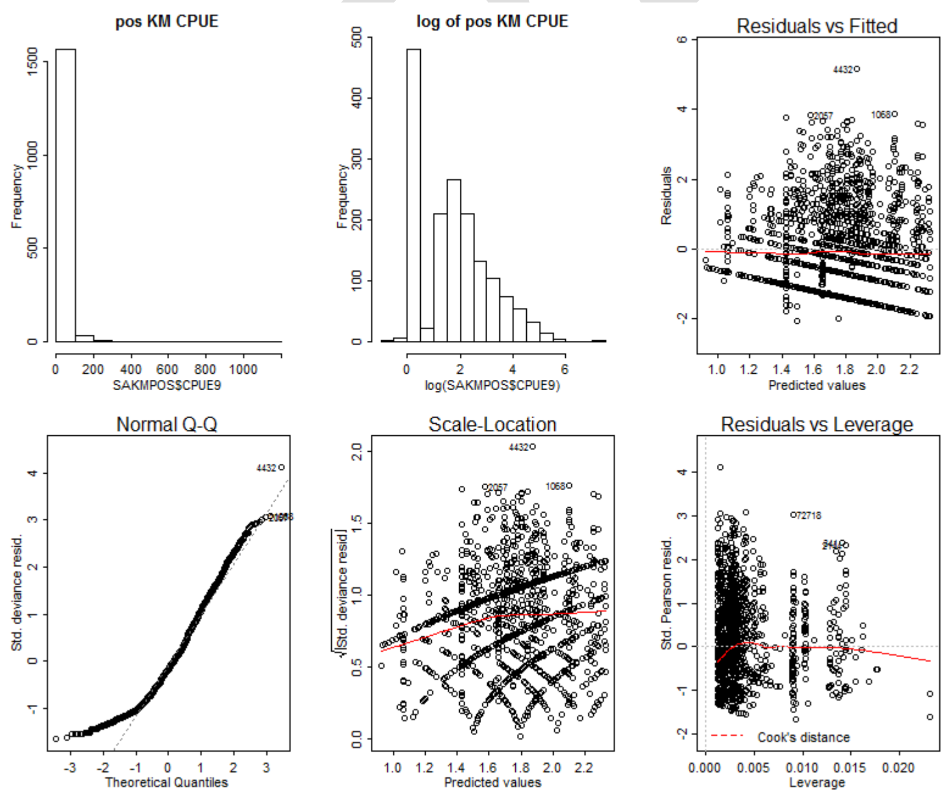


Figure 4. South Atlantic shrimp fishery discards (95%CI) and effort in numbers of trips (green line). Time series in blue is derived from an average catch rate per trip multiplied by the number of trips and are not model-derived estimates. Estimates include a correction for a 27% BRD reduction in 1999. The grey line indicates the estimates with no correction.

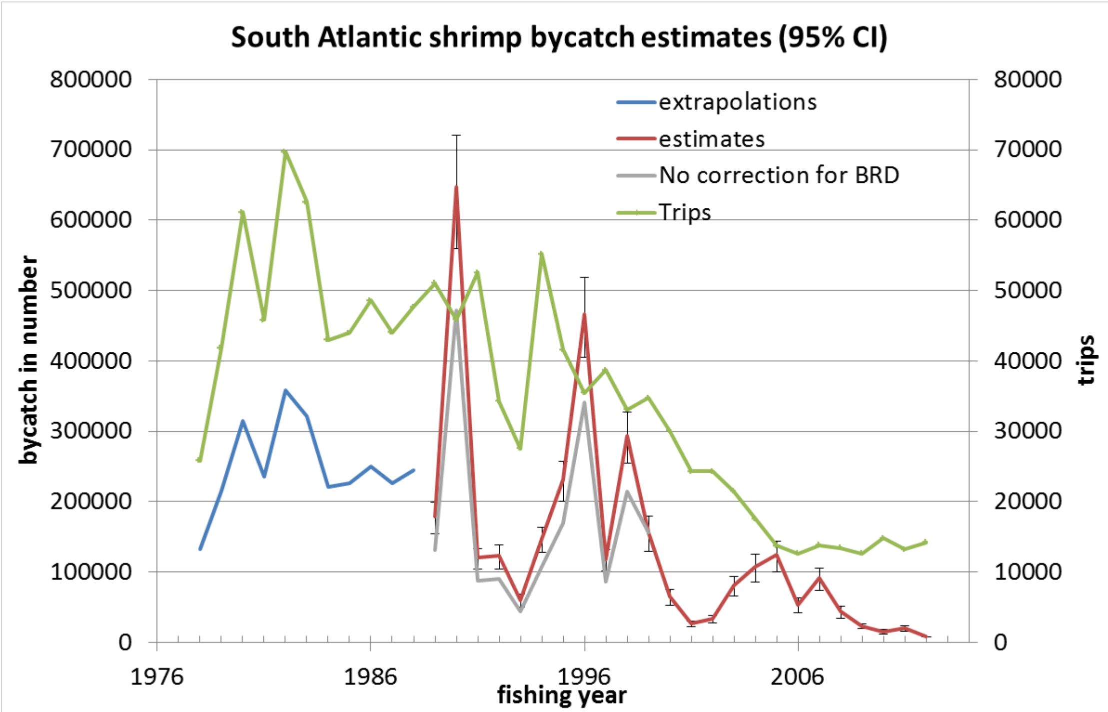
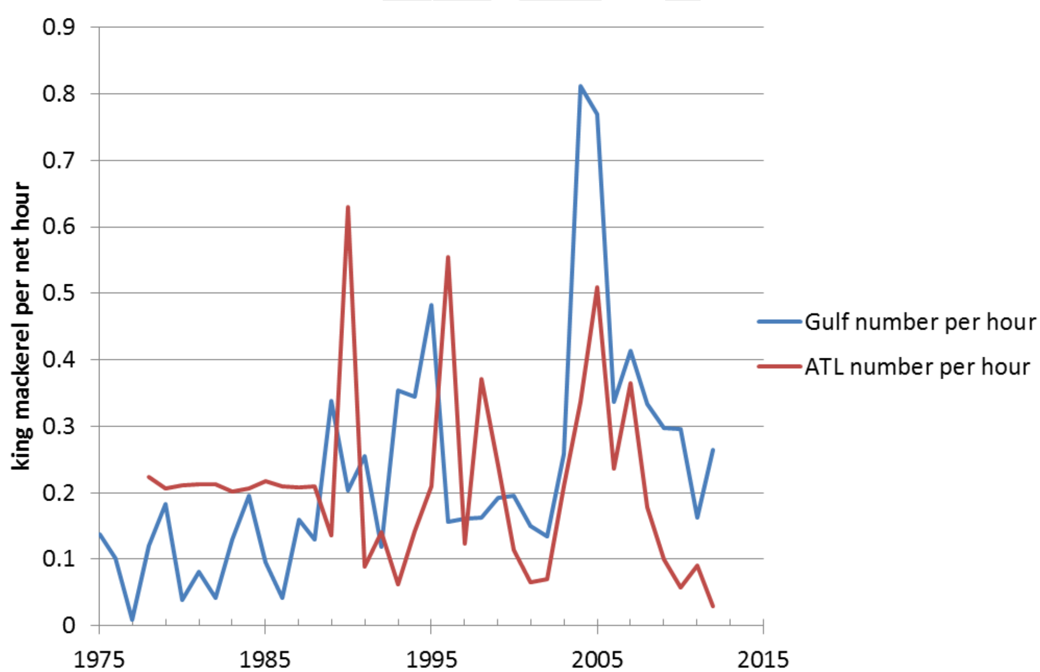


Figure 5. Comparison of estimated Gulf of Mexico and South Atlantic commercial shrimp trawl bycatch per net hour of king mackerel.



Appendix 1. Shrimp trawl observer database project codes. Note that projects A, C, W, X, Y were used in this project.

Trip No. :. The trip number consists of five or six characters: The first character refers to the organization conducting the project.

G = NMFS, Galveston Laboratory
F = Foundation, Gulf of Mexico
S = Foundation, South Atlantic
State Resource Agency

T = Texas Shrimp Association
D = Georgia DNR
N = North Carolina Sea Grant/

The second character refers to the project type.

<u>By-Catch Project Types</u>:

A = South Atlantic Mandatory Penaeid Shrimp
B = BRD Evaluation
C = Bycatch Characterization
D = Deep Water Royal Red
E = Effort

F = Flynet
G = BRD Certification, Gulf of Mexico
H = North Carolina Blue Crab
I = Skimmer Trawl (Manditory)
L = Experimental Skimmer (TED evaluations)

M = Modified Bycatch Characterization
N = Naked Net (TED alternative)
R = Red Snapper Initiative/
Gulf Mandatory Penaeid Shrimp
S = BRD Certification, South
Atlantic
T = TED Evaluation
W = South Atlantic
Mandatory Rock Shrimp
X = Rock Shrimp Characterization
Y = Rock Shrimp BRD Evaluation
Z = Soft TED Evaluation

Appendix 2. Shrimp trawl observer database net performance operation codes. Note that Z, Y and P were used for this estimation.

A - Nets not spread; typically doors are flipped or doors hung together so net could not spread.
B - Gear bogged; the net has picked up a large quantity of sand, clay, mud, or debris in the tail bag possibly affecting trawl performance.
C - Bag obstructed; the catch in the net is prevented from getting into the bag by something (i.e. grass, sticks, turtle, tires, metal/plastic containers etc.) or constriction of net (i.e. twisting of the lazy-line around net).
D - Gear not digging; the net is fishing off the bottom due to insufficient weight or not enough cable let out (etc.).
E - Twisted warp or line; the cables composing the bridle get twisted (from passing over blocks which occasionally must be removed before continuing to fish). Use this code if catch was affected.
F - Gear fouled; the gear has become entangled in itself or with another net. Typically this involves the webbing and some object like a float or chains or lazy line (etc.).
G -Bag untied; bag of net not tied when dragging net.
H - Rough weather. Bags mixed due to rough seas (too dangerous to separate); if the weather is so bad fishing is stopped, then the previous tow should receive this code if the rough conditions affected the catch.
I - Torn, damaged, or lost net; usually results from hanging the net and tearing it loose. The net comes back with large tears etc. if at all. Do not use this code if there are only a few broken meshes. Continue using this code until net is repaired or replaced
J - Dumped catch; tow was made but catch was discarded, perhaps because of too mud. Give reason in comments.

K - Catch not emptied on deck; nets brought to surface, boat changes location, nets redeployed. (explain in comments)
L - Hung up; untimely termination of a tow by a hang. Specify trawl(s) which were hung and caused lost time in Comments.
M - Bags dumped together, catches could not be kept separate.
N - Net did not fish; no apparent cause. Describe reasoning in comments.
O - Gear fouled on submerged object but tow was not terminated. Performance of tow could be affected. Give specifics in Comments.
P - No measurement taken of shrimp and/or total catch.
Q - Main cable breaks and entire rigging lost. Describe in Comments.
R - Net caught in wheel.
S - Tickler chain heavily fouled, tangled, or broken.
T - Other problems. Describe in comments.
U - Turtle excluder gear intentionally disabled.
V – Unknown operation code.
W - Damaged (i.e., bent or broken) excluder gear.
X - BRD intentionally disabled or non-functional. (Damaged) Describe in comments.
Y - Net trailing behind try net.
Z - Successful tow.