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Abstract

Shrimp bycatch estimates for South Atlantic king mackerel were generated using the same R generalized linear modeling (GLM) approach developed by Walter and Isely and used in the SEDAR 38 South Atlantic king mackerel assessment. This South Atlantic R GLM shrimp bycatch approach using a combination of observer data and SEAMAP scientific sampling similar to the Gulf of Mexico WINBUGS Bayesian shrimp bycatch approach developed by Nichols. Estimates of shrimp fishery discards for fishing years of 1972-2017 range from 15,754-433,096 age-0 king mackerel without BRD correction and range from 15,754-593,341 age-0 king mackerel with 27% BRD correction, respectively.

Methods

Datasets

Several datasets were used to estimate shrimp bycatch catch per unit effort (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 some overlap in the use/non-use of BRDs so its effect could be estimated and applied to the South Atlantic. 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)) (see Walter and Isely 2014 for detailed description on accounting for the effect of bycatch reduction devices). Many tows were from the rock shrimp fishery which operates deeper than 30 fathoms and for which catch rates of king mackerel were extremely low, but not zero (Table 2).

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 3.43 fish per net hour with 22% positive tows (Table 2). For the observer dataset, the average catch rates were about 0.49 fish per net hour with a 7% positive rate. The spatial coverage of the SEAMAP survey was relatively extensive and overlapped the fishery (Figure 1). Most of the observed shrimp effort is confined to a narrow area along the coast in waters (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.

Modeling

Shrimp bycatch estimates for South Atlantic king mackerel were generated using the same R GLM approach developed by Walter and Isely and used in the SEDAR 38 South Atlantic king mackerel assessment (Walter and Isely 2014). This South Atlantic R GLM shrimp bycatch approach using a combination of observer data and SEAMAP scientific sampling similar to the Gulf of Mexico WINBUGS Bayesian shrimp bycatch approach developed by Nichols (2004a, 2004b, 2006). A brief summary of the data sources and model is provided in this report, while a more detailed description can be found in Walter and Isely (2014).

The initial (and also, after model selection, final) models tested are shown below:

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

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

where POS is positive tow, SAKM is positive and negative binary catch dataset, HRSFISHD is hours fished per tow, CPUE9 is catch per unit effort, SAKMPOS is positive CPUE dataset. The model factors of YR, AR, DP, SES and DSET are defined in Table 3.

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 submodel 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.

All annual bycatch and effort estimates are reported or estimated in South Atlantic fishing year definition (March 1-February 28).

Shrimp effort estimation

Sources of shrimp effort data have been discussed in SEDAR38-RW-01 (Walter and Isely 2014). 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 net-hour fished, it was necessary to obtain the average hours fished per trip and average nets per tow (SEDAR28-AW02 2012, Walter and Isely 2014).

In this SEDAR38update, the 2013-2017 shrimp effort data were combined with the existing SEDAR38 1978-2012 shrimp effort data to form a combined shrimp effort dataset from 1978 to 2017 (Table 4). The 2013-2017 shrimp effort data were derived from shrimp effort data provided by FSD/SEFSC.

In this SEDAR38update, the 2011-2017 average hours fished per trip data were combined with the existing SEDAR38 1978-2010 (note: 2011 and 2012 values were averages for the last 3 years) hours fished per trip data to form a combined hours fished per trip dataset from 1978 to 2017 (Table 5). The 2011-2017 average hours fished per trip data were derived from shrimp effort data provided by FSD/SEFSC.

In this SEDAR38update, the 1979-2017 average nets per tow were calculated from Vessel Operating Units File (VOUF) provided by FSD/SEFSC (Table 6).

A brief summary of the procedure for the rock shrimp effort partition is provided in this report, while a more detailed description can be found in Walter and Isely (2014). 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 depth zones (i.e. 0-10 fathoms, 10-30 fathoms and 30+ fathoms) fished in the observed trips. Fraction of effort in 30+ fathom depth zone (<<1% of total shrimp effort) was allocated to rock shrimp based on the proportion of the annual rock shrimp landings to total shrimp landings (generally ~0.8%). As did for 2013 for the SEDAR 38, the average proportion of the annual rock shrimp landings to total shrimp landings (1978-2012) was used for 2014-2017 for the SEDAR38 update. In general this exercise of properly partitioning effort to depth zone and target species was relatively inconsequential for king mackerel bycatch.

For modeling the shrimp fishery in Stock Synthesis a time series of historical shrimp effort was developed (Table 7 and 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. 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.

Results and discussion

Model fits

For the logistic submodel, all model factors were significant (Table 8). 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 (Table 9). 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.

Estimated bycatch

Estimates of shrimp fishery discards for fishing years of 1972-2017 range from 15,754-433,096 age-0 king mackerel without BRD correction and range from 15,754-593,341 age-0 king mackerel with 27% BRD correction, respectively (Tables 10 and Figure 4). 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.

A mandatory observer program for the commercial shrimp fishery operating in the U.S. Gulf of Mexico was implemented in 2007. In June 2008, observer coverage expanded to include the South Atlantic *penaeid* and rock shrimp fisheries through Amendment 6 to the Shrimp Fishery Management Plan for the South Atlantic Region. The Gulf of Mexico WINBUGS Bayesian shrimp bycatch approach was developed prior to the mandatory shrimp observer program. Therefore, this approach might be the 'best' practice during that time for the available poor-quality data. As Nichols (2006) pointed out "all the analytical manipulations cannot completely overcome the limitations imposed by the underlying data. The observer data are still sparse, unbalanced, and non-random. Lack of randomness is a within-cell issue. There are no analytical actions that can make the data more representative, or even evaluate how representative the data are". Both the available shrimp fishery bycatch data and commercial fleet representation through stratified selection have substantially improved since mandatory observer coverage of the shrimp fleet began in 2007. In the next benchmark or research track assessment, we might need to re-visit/modify both the Gulf of Mexico WINBUGS Bayesian shrimp bycatch approach and South Atlantic R GLM shrimp bycatch approach by modeling the data from the poor-quality period and good-quality period (since mandatory observer program) separately. Given the South Atlantic R GLM shrimp bycatch approach using a combination of observer data and SEAMAP scientific sampling similar to the Gulf of Mexico WINBUGS Bayesian shrimp bycatch approach, it might be worthwhile to compare these two shrimp bycatch approaches.

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Table 1. Datasets used in the estimation of shrimp bycatch CPUES for the Gulf and South Atlantic. Sets 3-12 are historical datasets and do not need to be updated.

Set	BRD	Use	Gulf/SA	DSET	CPUE Name	Description
1	No	Yes	Gulf	R	OREGON1	Research SEAMAP Gulf trawl survey, 1972-
2	No	Yes	SA	SEAMAP	SEAMAP_ATL	Research SEAMAP Atlantic trawl survey, 1989-
3	No	Yes	Gulf	C	COLDOBS1	Old Observer, 1972-1985, assume no BRDs or TEDs
4	No	Yes	Gulf	C	RRPCHAR1	Historical Observer, 1992-1997, characterization
5	No	Yes	Gulf	C	RRPEVAL1	Historical Observer, 1992-1997, paired RRPBRDS1
6	No	Snapper only	Gulf	C	RRPONLY1	Historical Observer, 1992-1997, paired RRPBNLY1
7	Yes	Yes	Gulf	B	RRPBRDS1	Historical Observer, 1992-1997, paired RRPEVAL1
8	Yes	Snapper only	Gulf	B	RRPBNLY1	Historical Observer, 1992-1997, paired RRPONLY1
9	No	Yes	Gulf	C	FDEVAL1	BRD study, 1998, paired FDBRDS1
10	Yes	Yes	Gulf	B	FDBRDS1	BRD study, 1998, paired FDEVAL1
11	Yes	Snapper only	Gulf	B	FDBNLY1	BRD study, 1998, paired FDONLY1
12	No	Snapper only	Gulf	C	FDONLY1	BRD study, 1998, paired FDBNLY1
13	No	Snapper only	Gulf/SA	C	MOACO1	SIXTH SET, Modern Observer, 1997-, paired MOAEO1
14	Yes	Snapper only	Gulf/SA	B	MOAEO1	FIFTH SET, Modern Observer, 1997-, paired MOACO1
15	Yes	Yes	Gulf/SA	B	MOAEB1	THIRD SET, Modern Observer, 1997-, paired MOACN1
16	No	Yes	Gulf/SA	C	MOACN1	FOURTH SET, Modern Observer, 1997-, paired MOAEB1
17	Yes	Snapper only	Gulf	B	MOECB1	SECOND, EFFORT PROJECT, 1999-2010, CTRL
18	Yes	Snapper only	Gulf	B	MOEEB1	FIRST SET, EFFORT PROJECT, 1999-2010, EXPTL

DSET C: Commercial vessel with no-BRD

DSET D: Commercial vessel with BRD

DEST R: Research vessel Oregon II of SEAMAP Gulf trawl survey

DEST SEAMAP: Research vessel SEAMAP Atlantic trawl survey

Table 2. Observed number of tows, percentage of positive tows and catch per unit efforts (CPUES in number of fish per net-hour) from datasets commercial vessel without BRD, commercial vessel with BRD, commercial rock shrimp vessel with/without BRD and research vessel SEAMAP Atlantic trawl survey in South Atlantic.

	Tows				Percebtage positive				CPUE (fish/net-hour)			
Year	BRD	no_BRD	Rock Shrimp	SEAMAP_ATL	BRD	no_BRD	Rock Shrimp	SEAMAP_ATL	BRD	no_BRD	Rock Shrimp	SEAMAP_ATL
1989				265				23.40%				1.681
1990				231				42.42%				6.552
1991				233				20.17%				1.101
1992				234				19.66%				5.808
1993				234				19.66%				1.814
1994				234				21.37%				2.256
1995				234				28.21%				5.699
1996				234				34.62%				7.814
1997				234				20.09%				1.231
1998				234				27.78%				7.910
1999				234				32.91%				2.237
2000				234				22.65%				3.231
2001	30		15	306	13.33%		0.00%	17.32%	0.533		0.000	2.365
2002	13		108	306	0.00%		0.93%	21.24%	0.000		0.007	1.431
2003			172	306			5.81%	25.16%			0.191	3.353
2004				305				23.93%				4.348
2005	156			306	23.72%			19.28%	2.871			5.441
2006			22	306			0.00%	19.93%			0.000	3.696
2007	135			306	14.81%			22.55%	0.785			3.652
2008	240		111	306	2.50%		0.00%	16.34%	0.185		0.000	5.181
2009	451		19	336	8.87%		0.00%	16.67%	0.699		0.000	2.107
2010	184		57	336	0.00%		1.75%	13.39%	0.000		0.105	0.933
2011	322			336	2.17%			11.90%	0.077			2.652
2012	373	2		336	0.54%	0.00%		14.29%	0.014	0.000		1.607
2013	293		95	295	2.73%		0.00%	18.64%	0.089		0.000	1.129
2014	176		37	306	5.68%		0.00%	16.34%	0.381		0.000	2.387
2015	273		48	329	3.66%		0.00%	18.54%	0.067		0.000	2.216
2016	389		73	331	13.88%		0.00%	28.40%	1.011		0.000	9.648
2017	374		44	294	12.57%		0.00%	28.23%	0.525		0.000	1.811
Totals or Averages	3409	2	801	8181	7.19%	0.00%	1.50%	21.72%	0.487	0.000	0.049	3.434

Table 3. List of factor levels for the main effects of the R generalized linear shrimp bycatch estimation model.

Main Effect	Levels	Description
YR	29	1989-2017
SEA	3	Jan-Apr, May-Aug, Sep-Dec
AR	4	FL, GA, SC, NC
DP	3	<= 10fm, >10fm & <=30fm, >30fm
DST	3	Observer programs BRD, Rock shrimp, Research vessel

Table 4. Effort estimates in number of trips. The average of NC 1992 and 1994 was used to fill the missing value of NC 1993. January 1-Feburary 28 portion 2018 of 2017 fishing year estimates are not complete but use an average for the last three years for the missing months.

FishingYR	FL	GA	SC	NC	Grand Total
1978		11284		13629	24913
1979		14481	11357	16281	42119
1980		12897	14587	32702	60185
1981	4810	6770	8899	24897	45376
1982	5173	11928	13982	37860	68944
1983	5250	11606	10398	36367	63622
1984	4732	5551	5615	27300	43197
1985	5181	7935	5472	24551	43139
1986	4353	10111	10058	23999	48522
1987	4251	9235	11342	19285	44113
1988	4924	8813	8329	25468	47533
1989	5272	7555	10142	29091	52059
1990	6443	7093	9934	20323	43793
1991	5513	9866	13960	24229	53568
1992	4690	8752	12319	9569	35329
1993	5468	8934	11426	13082	38910
1994	6590	8739	10465	16599	42392
1995	5509	9528	11756	16363	43156
1996	5839	7899	9160	11899	34797
1997	5283	8998	11325	13319	38924
1998	5114	8117	9556	9784	32569
1999	4946	6911	9957	13578	35391
2000	3588	5040	9365	12718	30709
2001	3277	3387	6463	10235	23361
2002	2783	3507	6906	12008	25204
2003	2744	3468	6303	8989	21503
2004	2773	2752	5926	6176	17626
2005	2694	2436	4161	4341	13631
2006	2477	2051	3627	4371	12526
2007	2245	1642	3292	6673	13850
2008	2201	1792	3525	5904	13421
2009	2149	1763	3175	5679	12765
2010	2749	2200	4326	5485	14760
2011	2839	2081	3308	4504	12731
2012	2342	1750	4095	6187	14373
2013	1808	1323	3173	5361	11664
2014	2061	1597	3126	4383	11167
2015	1827	1435	3964	6209	13435
2016	1779	912	3339	7747	13776
2017	1876	920	2799	7956	13551

Table 5. Hours fished per trip. 1978-2010 values were from SEDAR38 1978-2010 and 2011-2017 values were derived from shrimp effort data provided by FSD/SEFSC.

Year	FL	GA	SC	NC
1978	18.45	28.04	14.84	18.32
1979	18.45	28.04	14.84	18.32
1980	18.45	28.04	14.84	18.32
1981	18.45	28.04	14.84	18.32
1982	18.45	28.04	14.84	18.32
1983	18.45	28.04	14.84	18.32
1984	18.45	28.04	14.84	18.32
1985	20.70	28.04	14.84	18.32
1986	16.81	28.04	14.84	18.32
1987	17.85	28.04	14.84	18.32
1988	17.89	28.04	14.84	18.32
1989	17.57	28.04	14.84	18.32
1990	18.48	28.04	14.84	18.32
1991	15.14	28.04	14.84	18.32
1992	16.10	28.04	14.84	18.32
1993	16.39	28.04	14.84	18.32
1994	15.69	28.04	14.84	18.32
1995	14.87	28.04	14.84	18.32
1996	13.67	28.04	14.84	18.32
1997	12.40	28.04	14.84	18.32
1998	14.48	28.04	14.84	18.32
1999	13.61	28.04	14.84	18.32
2000	13.34	28.04	14.84	18.03
2001	14.07	28.04	14.84	17.70
2002	14.46	28.10	14.84	19.21
2003	20.48	28.36	14.11	15.56
2004	19.98	27.66	17.71	19.72
2005	19.13	24.27	12.71	16.14
2006	17.27	24.38	12.10	16.46
2007	16.53	23.83	10.69	17.57
2008	15.41	22.13	10.01	21.18
2009	15.34	23.74	11.33	17.79
2010	15.82	21.78	11.06	17.05
2011	74.39	111.10	12.43	12.67
2012	88.80	26.28	9.69	12.06
2013	89.79	26.53	8.11	12.00
2014	84.47	25.08	13.74	12.00
2015	93.92	36.26	12.07	12.00
2016	85.72	41.72	9.83	12.00
2017	94.50	53.63	99.00	12.00

Table 6. Number of nets per vessel in the South Atlantic shrimp fishery calculated from Vessel Operating Units File data. Missing data in GA (2002, 2007, 2015), SC (2004, 2005, 2006) and NC (2003, 2004, 2007) were filled with the average from the same state in the two years preceding and following the empty state year.

Year	FL	GA	SC	NC
1979	2.08	2.14	2.01	1.99
1980	2.10	2.19	1.97	2.01
1981	2.15	2.19	1.96	2.02
1982	2.15	2.21	1.97	2.05
1983	2.20	2.23	1.97	2.05
1984	2.22	2.29	2.03	2.06
1985	2.24	2.42	2.10	2.18
1986	2.51	2.44	2.17	2.22
1987	2.66	2.56	2.27	2.20
1988	2.60	2.64	2.28	2.25
1989	2.83	2.72	2.23	2.46
1990	2.99	2.75	2.20	2.54
1991	2.77	2.77	2.29	2.61
1992	2.41	2.78	2.29	2.57
1993	2.90	2.85	2.29	2.58
1994	2.88	2.84	3.54	2.53
1995	2.78	2.89	3.50	2.49
1996	2.80	2.89	3.54	2.41
1997	2.92	2.90	3.53	2.00
1998	2.89	2.89	3.62	2.00
1999	3.04	2.85	3.60	2.00
2000	3.10	2.86	3.52	2.00
2001	3.31	3.11	3.63	2.00
2002	3.33	2.98	1.00	2.00
2003	3.42	3.06	3.57	2.48
2004	3.33	2.87	2.72	2.48
2005	3.02	2.78	2.72	1.00
2006	3.17	2.61	2.72	2.48
2007	3.35	2.88	3.20	3.03
2008	3.38	3.09	3.11	2.91
2009	3.10	3.04	3.19	3.08
2010	3.16	2.89	3.18	3.04
2011	3.10	3.07	3.17	3.13
2012	3.63	3.14	3.16	3.02
2013	3.21	2.77	2.99	3.00
2014	2.00	3.08	3.09	3.09
2015	2.00	3.18	3.02	3.12
2016	2.00	3.46	2.90	3.07
2017	3.47	3.42	2.90	3.00

Table 7. Time series of shrimp effort in number of trips (1928-2017) for modeling the shrimp fishery in Stock Synthesis.

FishingYR	TRIPS		FishingYR	TRIPS		FishingYR	TRIPS
1928	0		1963	42406		1998	32569
1929	250		1964	42406		1999	35391
1930	500		1965	42406		2000	30709
1931	750		1966	42406		2001	23361
1932	1000		1967	42406		2002	25204
1933	1250		1968	42406		2003	21503
1934	1500		1969	42406		2004	17626
1935	1750		1970	42406		2005	13631
1936	2000		1971	42406		2006	12526
1937	2267		1972	42406		2007	13850
1938	2533		1973	42406		2008	13421
1939	2800		1974	42406		2009	12765
1940	0		1975	42406		2010	14760
1941	0		1976	42406		2011	12731
1942	0		1977	42406		2012	14373
1943	267		1978	24913		2013	11664
1944	533		1979	42119		2014	11167
1945	4400		1980	60185		2015	13435
1946	5460		1981	45376		2016	13776
1947	6520		1982	68944		2017	13551
1948	7580		1983	63622			
1949	8640		1984	43197			
1950	9700		1985	43139			
1951	10760		1986	48522			
1952	11820		1987	44113			
1953	12880		1988	47533			
1954	13940		1989	52059			
1955	15000		1990	43793			
1956	16500		1991	53568			
1957	18000		1992	35329			
1958	20000		1993	38910			
1959	23000		1994	42392			
1960	28000		1995	43156			
1961	29600		1996	34797			
1962	30000		1997	38924			

Table 8. Binomial model.

```
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         -6.77582    0.21187 -31.980  < 2e-16 ***
YR1990         -5.67617    0.20367 -27.870  < 2e-16 ***
YR1991         -6.96248    0.22577 -30.839  < 2e-16 ***
YR1992         -6.95741    0.22672 -30.688  < 2e-16 ***
YR1993         -6.99418    0.22664 -30.860  < 2e-16 ***
YR1994         -6.80356    0.22315 -30.489  < 2e-16 ***
YR1995         -6.40948    0.21275 -30.126  < 2e-16 ***
YR1996         -6.00492    0.20688 -29.027  < 2e-16 ***
YR1997         -6.87328    0.22585 -30.433  < 2e-16 ***
YR1998         -6.35311    0.21127 -30.071  < 2e-16 ***
YR1999         -6.03436    0.20630 -29.250  < 2e-16 ***
YR2000         -6.71544    0.22054 -30.450  < 2e-16 ***
YR2001         -7.21237    0.20717 -34.814  < 2e-16 ***
YR2002         -6.87188    0.20200 -34.020  < 2e-16 ***
YR2003         -6.45671    0.19639 -32.878  < 2e-16 ***
YR2004         -6.59587    0.20143 -32.745  < 2e-16 ***
YR2005         -6.32991    0.18144 -34.886  < 2e-16 ***
YR2006         -6.92719    0.20798 -33.307  < 2e-16 ***
YR2007         -6.47156    0.18785 -34.452  < 2e-16 ***
YR2008         -7.31287    0.20120 -36.347  < 2e-16 ***
YR2009         -7.02336    0.16856 -41.666  < 2e-16 ***
YR2010         -7.58724    0.21320 -35.588  < 2e-16 ***
YR2011         -7.61771    0.20904 -36.442  < 2e-16 ***
YR2012         -7.60780    0.20268 -37.536  < 2e-16 ***
YR2013         -7.21991    0.19668 -36.708  < 2e-16 ***
YR2014         -7.24788    0.19920 -36.386  < 2e-16 ***
YR2015         -7.35235    0.18318 -40.137  < 2e-16 ***
YR2016         -6.32122    0.15810 -39.983  < 2e-16 ***
YR2017         -6.73018    0.15631 -43.057  < 2e-16 ***
AR6            -1.18323    0.07895 -14.986  < 2e-16 ***
AR7            -1.40732    0.07668 -18.353  < 2e-16 ***
AR8            -1.95946    0.09909 -19.775  < 2e-16 ***
DP2            -1.26749    0.37849  -3.349 0.000812 ***
DP3            -3.09401    1.08912  -2.841 0.004499 ** 
SEAS2           1.27798    0.10974  11.645  < 2e-16 ***
SEAS3           2.51208    0.10856  23.139  < 2e-16 ***
DSETRS         -2.18568    0.40981  -5.333 9.64e-08 ***
DSETSEAMAP_ATL  4.72067    0.09119  51.769  < 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: 38687.5  on 12393  degrees of freedom
Residual deviance:  9005.6  on 12355  degrees of freedom
AIC: 9081.6

Number of Fisher Scoring iterations: 8
```

Table 9. Lognormal model.

```
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          0.85242    0.21853   3.901 9.91e-05 ***
YR1990          1.35503    0.19890   6.813 1.27e-11 ***
YR1991          0.69530    0.23186   2.999 0.002744 ** 
YR1992          1.33035    0.23385   5.689 1.47e-08 ***
YR1993          0.70691    0.23113   3.058 0.002254 ** 
YR1994          1.04879    0.22870   4.586 4.80e-06 ***
YR1995          1.22829    0.21253   5.779 8.68e-09 ***
YR1996          1.43298    0.20444   7.009 3.26e-12 ***
YR1997          0.87089    0.21722   4.009 6.31e-05 ***
YR1998          1.63395    0.21501   7.599 4.55e-14 ***
YR1999          0.97320    0.20016   4.862 1.25e-06 ***
YR2000          1.05654    0.22351   4.727 2.44e-06 ***
YR2001          0.84779    0.21517   3.940 8.43e-05 ***
YR2002          0.75232    0.20433   3.682 0.000238 ***
YR2003          1.12414    0.20419   5.505 4.16e-08 ***
YR2004          1.47356    0.20127   7.321 3.54e-13 ***
YR2005          1.75073    0.18365   9.533  < 2e-16 ***
YR2006          1.55637    0.20925   7.438 1.51e-13 ***
YR2007          1.58611    0.19022   8.338  < 2e-16 ***
YR2008          1.86074    0.21540   8.638  < 2e-16 ***
YR2009          1.21458    0.17947   6.768 1.71e-11 ***
YR2010          0.88772    0.23413   3.792 0.000154 ***
YR2011          1.38825    0.22545   6.158 8.90e-10 ***
YR2012          0.59002    0.21985   2.684 0.007340 ** 
YR2013          0.65111    0.21005   3.100 0.001964 ** 
YR2014          1.23394    0.20546   6.006 2.26e-09 ***
YR2015          0.99094    0.20052   4.942 8.39e-07 ***
YR2016          1.37391    0.16127   8.519  < 2e-16 ***
YR2017          0.88617    0.16138   5.491 4.50e-08 ***
AR6            -0.68182    0.07128  -9.565  < 2e-16 ***
AR7            -0.74107    0.06879 -10.773  < 2e-16 ***
AR8            -0.19988    0.09877  -2.024 0.043145 *  
DP2             0.05907    0.38059   0.155 0.876669    
DP3            -0.96632    1.22879  -0.786 0.431725    
SEAS2           0.25097    0.12168   2.062 0.039291 *  
SEAS3           0.52730    0.11920   4.424 1.02e-05 ***
DSETRS         -0.65510    0.38556  -1.699 0.089456 .  
DSETSEAMAP_ATL  0.64094    0.09205   6.963 4.49e-12 ***
---
Signif. codes:  0 ‘***’ 0.001 ‘**’ 0.01 ‘*’ 0.05 ‘.’ 0.1 ‘ ’ 1

(Dispersion parameter for gaussian family taken to be 1.350126)

    Null deviance: 9055.0  on 2034  degrees of freedom
Residual deviance: 2694.9  on 1996  degrees of freedom
AIC: 6422.5

Number of Fisher Scoring iterations: 2
```

Table 10A. Estimated bycatch (95%CI) of age-0 king mackerel in the South Atlantic shrimp fishery without BRD correction. Values of 1978-1988 are obtained by multiplying the average number per trip over the entire time series by the number of trips in each year. January 1-Feburary 28 portion 2018 of 2017 fishing year estimates are not complete but use an average for the last three years for the missing months.

FishingYR	TRIPS	Bycatch	SE	CV	LCI	UCI	NumberPerTrip
1978	24913	102717					4.12
1979	42119	173661					4.12
1980	60185	248151					4.12
1981	45376	187091					4.12
1982	68944	284264					4.12
1983	63622	262320					4.12
1984	43197	178107					4.12
1985	43139	177868					4.12
1986	48522	200061					4.12
1987	44113	181885					4.12
1988	47533	195983					4.12
1989	52059	78041	9492	0.12	61244	99444	1.50
1990	43793	433096	54612	0.13	336892	556773	9.89
1991	53568	51540	6398	0.12	40246	66002	0.96
1992	35329	76920	10406	0.14	58758	100695	2.18
1993	38910	50271	7161	0.14	37863	66745	1.29
1994	42392	95916	12308	0.13	74283	123848	2.26
1995	43156	159095	17986	0.11	126991	199315	3.69
1996	34797	254771	28856	0.11	203276	319311	7.32
1997	38924	60692	7415	0.12	47577	77421	1.56
1998	32569	205208	24386	0.12	161934	260047	6.30
1999	35391	145739	16781	0.12	115849	183341	4.12
2000	30709	62385	7490	0.12	49110	79250	2.03
2001	23361	27875	3492	0.13	21719	35776	1.19
2002	25204	27880	3308	0.12	22008	35319	1.11
2003	21503	83367	9996	0.12	65647	105870	3.88
2004	17626	100300	13373	0.13	76914	130797	5.69
2005	13631	126988	16886	0.13	97448	165484	9.32
2006	12526	49384	7150	0.14	37024	65870	3.94
2007	13850	85725	10205	0.12	67620	108678	6.19
2008	13421	48824	6898	0.14	36858	64676	3.64
2009	12765	29188	2979	0.10	23812	35777	2.29
2010	14760	15754	2347	0.15	11713	21188	1.07
2011	12731	86432	15136	0.18	61054	122360	6.79
2012	14373	38183	7251	0.19	26205	55636	2.66
2013	11664	45313	8199	0.18	31646	64882	3.89
2014	11167	54752	9434	0.17	38890	77084	4.90
2015	13435	39457	5784	0.15	29477	52816	2.94
2016	13776	141233	16692	0.12	111593	178746	10.25
2017	13551	91320	9777	0.11	73763	113056	6.74

Table 10B. Estimated bycatch (95%CI) of age-0 king mackerel in the South Atlantic shrimp fishery include a correction for a 27% BRD reduction since 1999. Values of 1978-1988 are obtained by multiplying the average number per trip over the entire time series by the number of trips in each year. January 1-Feburary 28 portion 2018 of 2017 fishing year estimates are not complete but use an average for the last three years for the missing months.

FishingYR	TRIPS	Bycatch27BRD	SE27BRD	CV27BRD	LCI27BRD	UCI27BRD	NumberPerTrip27BRD
1978	24913	140723					5.65
1979	42119	237915					5.65
1980	60185	339967					5.65
1981	45376	256315					5.65
1982	68944	389441					5.65
1983	63622	359379					5.65
1984	43197	244006					5.65
1985	43139	243679					5.65
1986	48522	274083					5.65
1987	44113	249183					5.65
1988	47533	268497					5.65
1989	52059	106916	13004	0.122	83905	136238	2.05
1990	43793	593341	74818	0.126	461541	762778	13.55
1991	53568	70609	8766	0.124	55137	90423	1.32
1992	35329	105380	14256	0.135	80499	137952	2.98
1993	38910	68871	9810	0.142	51872	91440	1.77
1994	42392	131405	16862	0.128	101768	169672	3.10
1995	43156	217960	24641	0.113	173977	273061	5.05
1996	34797	349036	39532	0.113	278487	437456	10.03
1997	38924	83147	10159	0.122	65180	106067	2.14
1998	32569	281135	33409	0.119	221849	356264	8.63
1999	35391	145739	16781	0.115	115849	183341	4.12
2000	30709	62385	7490	0.120	49110	79250	2.03
2001	23361	27875	3492	0.125	21719	35776	1.19
2002	25204	27880	3308	0.119	22008	35319	1.11
2003	21503	83367	9996	0.120	65647	105870	3.88
2004	17626	100300	13373	0.133	76914	130797	5.69
2005	13631	126988	16886	0.133	97448	165484	9.32
2006	12526	49384	7150	0.145	37024	65870	3.94
2007	13850	85725	10205	0.119	67620	108678	6.19
2008	13421	48824	6898	0.141	36858	64676	3.64
2009	12765	29188	2979	0.102	23812	35777	2.29
2010	14760	15754	2347	0.149	11713	21188	1.07
2011	12731	86432	15136	0.175	61054	122360	6.79
2012	14373	38183	7251	0.190	26205	55636	2.66
2013	11664	45313	8199	0.181	31646	64882	3.89
2014	11167	54752	9434	0.172	38890	77084	4.90
2015	13435	39457	5784	0.147	29477	52816	2.94
2016	13776	141233	16692	0.118	111593	178746	10.25
2017	13551	91320	9777	0.107	73763	113056	6.74

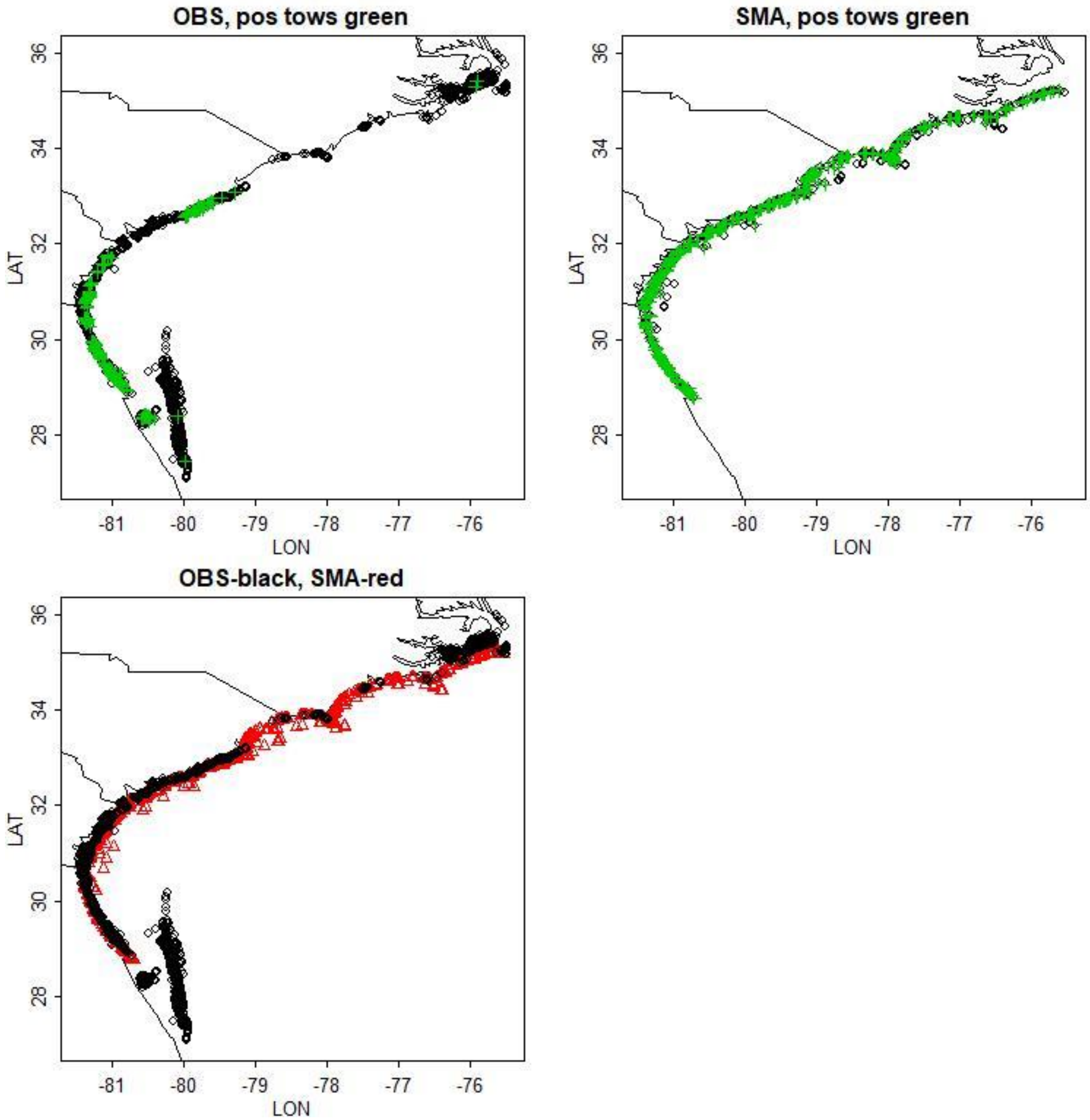

Figure 1. Spatial plots of shrimp observer data and SEAMAP data with positive tows shown in green and overlap of SEAMAP (red) and Observer (black).

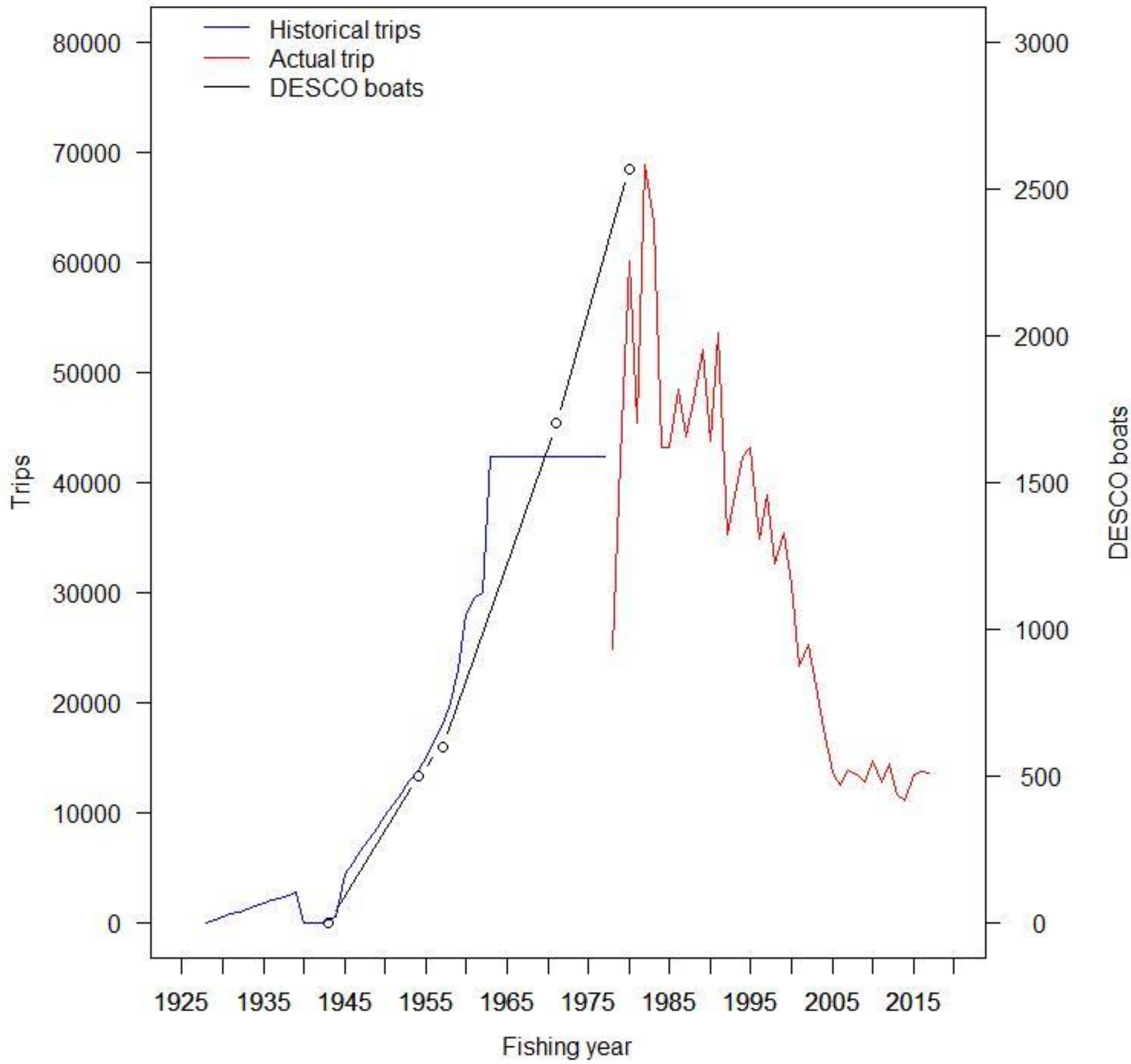

Figure 2. Time series of South Atlantic shrimp effort showing historical build up from 1928 and the substantial increases immediately after WWII commensurate with the boat building trends in the DESCO shipyard in St Augustine, FL. DESCO boat building trends come from: http://www.staugustinelighthouse.org/LAMP/Hertiage_Boatbuilding/

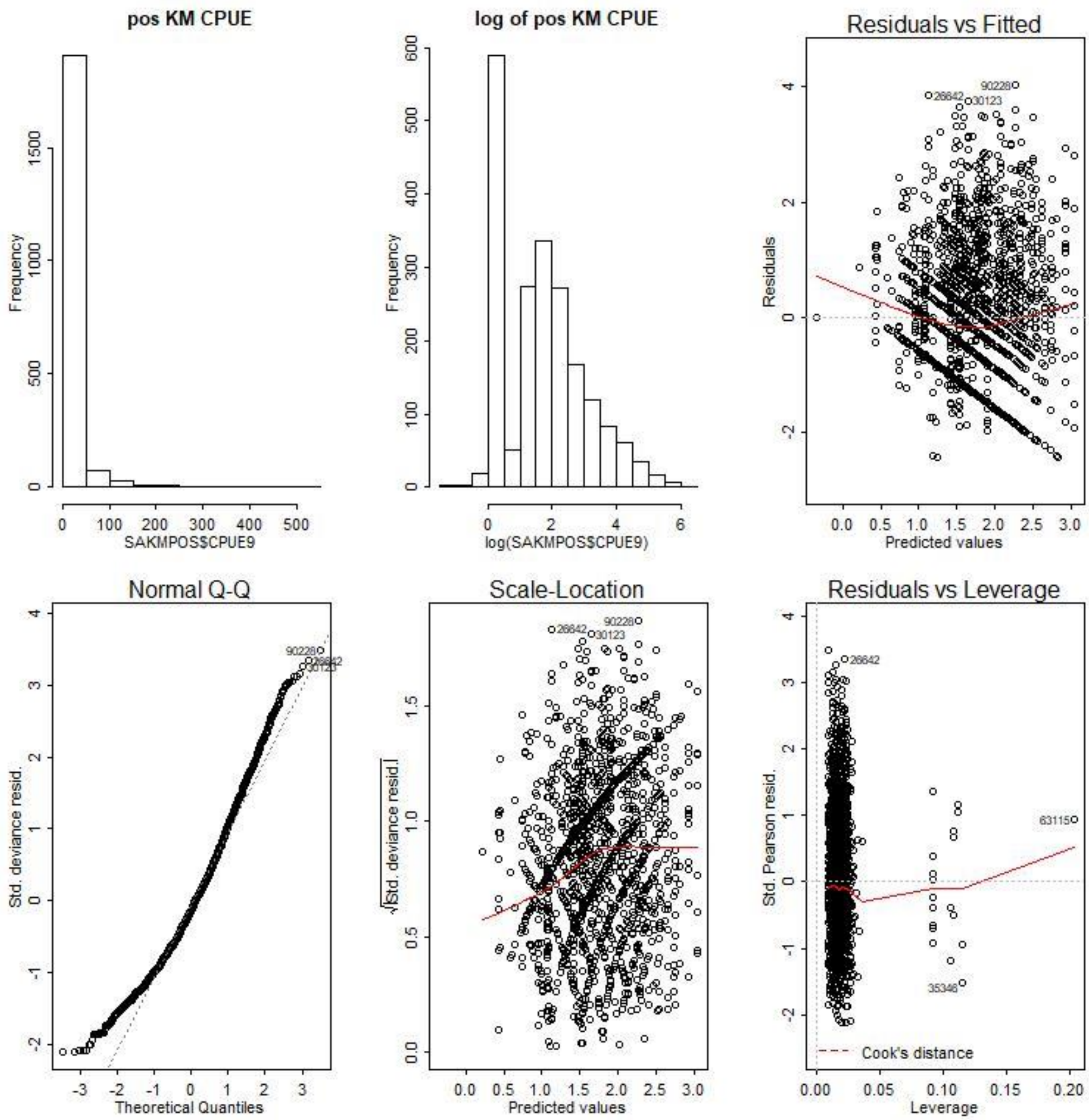

Figure 3. Plot of frequency distribution of positive CPUE, log of positive CPUE, residuals versus fitted values, normal q-q, scale versus location and leverage versus residual.

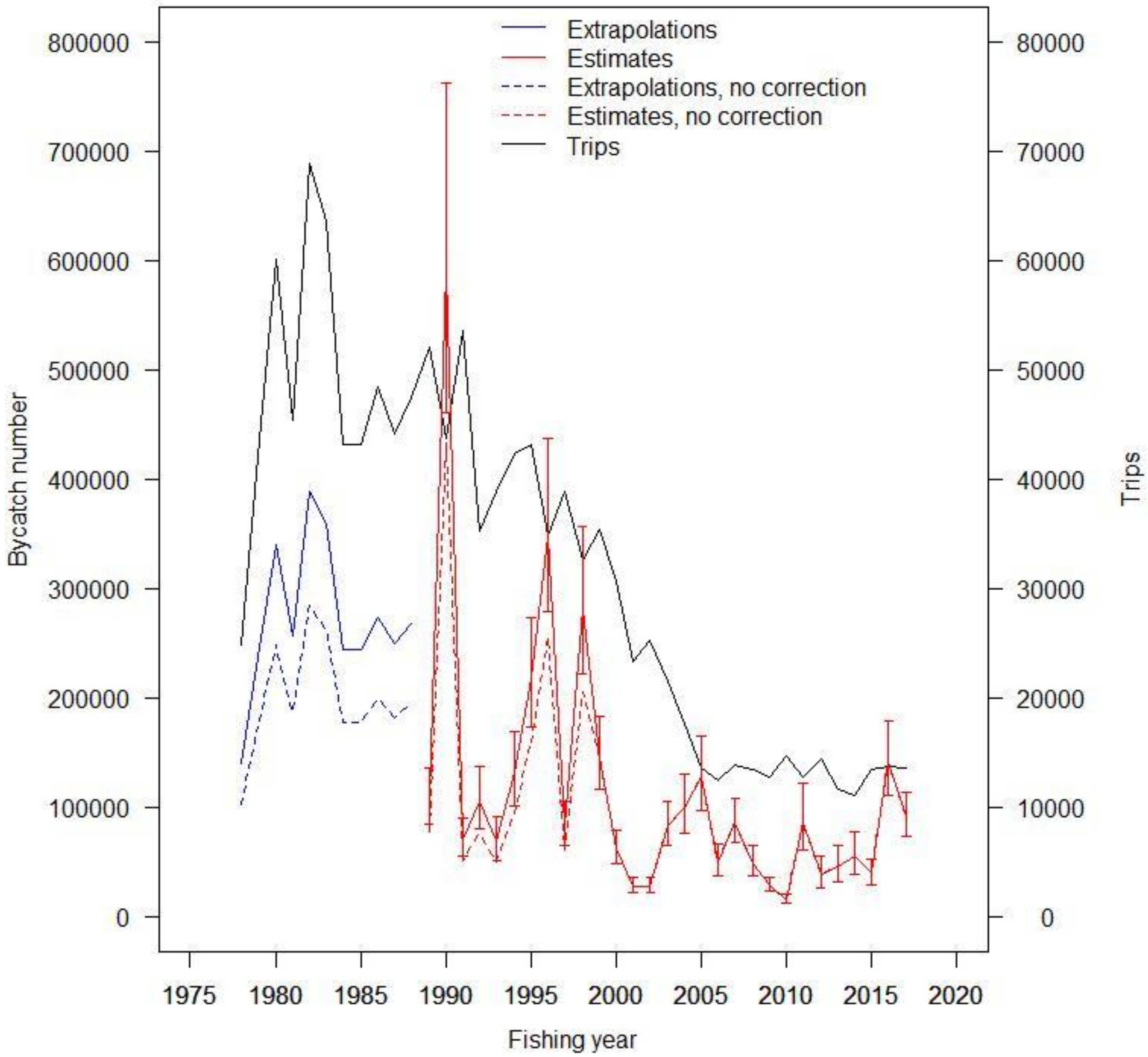

Figure 4. South Atlantic shrimp fishery discards (95%CI) and effort in numbers of trips (black line). Time series in blue are derived from an average catch rate per trip multiplied by the number of trips and are not model-derived estimates. Estimates include a correction for a 27% BRD reduction since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