An Update of Blacknose Shark Bycatch Estimates Taken by the Gulf of Mexico Penaeid Shrimp Fishery from 1972 to 2009

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INTRODUCTION

Bycatch estimation of blacknose shark (*Carcharchinus acronotus*) by the penaeid shrimp trawl fishery in the Gulf of Mexico, as of the last assessment (SEDAR13), used a model developed for the bycatch of red snapper (*Lutjanus campechanus*) run under the computer program WinBUGS (Spiegelhalter et al. 2003). Alternative models for the estimation of blacknose bycatch were not considered possibly because the extreme execution time (up to 70 hours) discouraged exploration of alternative models. The impact of Turtle Exclusion Devices (TEDs), which have been in widespread use since 1990, was not considered despite an expected ability to exclude fish the size of blacknose shark. Raborn et al. (2009) used a negative binomial regression model in a before-after-control-impact design to show that TEDs reduced substantially the catch rate for blacknose shark. Raborn (2009) also found that year effect was not important for the prediction of catch rate. Gazey et al. 2009 used AD Model Builder (ADMB 2010) to develop and evaluate six alternative Bayesian bycatch estimation models to address these issues.

The objective here is to update blacknose shark bycatch estimates taken by the Gulf of Mexico penaeid shrimp fishery over the period 1972 to 2009 using the methodologies developed by Gazey et al. 2009.

METHODS

The catch rate (number of blacknose shark captured per trawl net hour) data and effort information used in this analysis were provided by National Marine Fisheries Service (NMFS). The catch rate data came from both fishery independent and dependent sources. The fisheries independent sampling programs (Southeast Area Monitoring and Assessment Program [SEAMAP]), henceforth referred to as "research data", used standard 40-ft commercial shrimp trawls without bycatch reduction devices or TEDs. The fishery dependent observer programs, henceforth referred to as "observer data", were obtained from observers placed on commercial shrimp trawl vessels. By 1990 TEDs were in widespread use by the offshore commercial penaeid shrimping fleet.

For each trawl tow the duration of the tow and the number of blacknose shark caught were recorded. For some of the tows, a sub-sample of the catch was identified to species and the number of blacknose shark taken by the tow estimated. The trawl information was categorized into temporal and spatial strata consistent to that used by Nichols (2007); namely, 38 years (1972 – 2009), three trimesters (Jan-Apr, May-Aug, Sep-Dec), 4 areas (statistical reporting areas 1-9, 10-12, 13-17, 18-21), 2 depth zones (inside ten fathom, outside ten fathom), and three trawl data sources (observer without a TED, observer with a TED and research). The catch rate data were contained in the file scottHybrid-june2010.csv.

The number of boat-days and associated standard deviation were available for all strata described above (file SNCELL_1960-2009_for_Snpr_2_Depth.xls). The number of nets per vessel and the associated precision were available by year only. Therefore, we have assumed that the number of nets per vessel is consistent across trimester, area and depth zone within a year. We assumed a 24 hour day and independent effort measures by strata to compute net-hours for each stratum and the associated standard deviation.

All models applied to the data were derived and described by Gazey et al (2009). Parameter estimates were obtained through the software package ADMB (ADMB 2010). The package allows for the restriction or bounding of parameter values, stepwise optimization, the estimation of user defined variables, report production of standard errors and correlation between all estimated variables. We considered six alternative models based on with and without year, a pre-post 1990 time trend and TED effects, i.e.,

1. Year effect (each year has an associated parameter) without a TED effect. This model structure is similar to that used by Nichols (2007).
2. Year effect with a TED effect.

3. No year effect without a TED effect. This model assumes that shark catch rate by the shrimp fishery is proportional to shrimp effort in each area, trimester and depth zone.
4. No year effect with a TED effect.
5. Pre-post 1990 time trend without a TED effect.
6. Pre-post 1990 time trend with a TED effect.

The alternative models were evaluated through Akaike Information Criteria (AIC) following Burnham and Anderson (2004). Corrections for lack of fit and effective sample were not used in the comparison of models.

RESULTS

Overall, our analyses included data from 35,599 tows made in the Gulf of Mexico (Table 1). About 81% of the tows were designated as research tows. The duration of the observer tows (mean of 6.2 hours) was substantially longer than the research tows (mean of 0.3 hours) with few of the tows capturing one or more blacknose shark (0.5%, approximately, see Table 1). The 2009 SEAMAP (research) and observer sampling locations with and without the capture of blacknose shark are drawn in Figures 1 and 2, respectively. The 2009 plots of research and observer sampling locations serve to illustrate that an encounter with a blacknose shark is rare and sampling occurred over a wide geographical area. Also note the uniform spatial sampling of research tows in comparison to the clumped fishery dependent observer tows. The total number of tows and mean catch rate by year in the observer and research data are plotted in Figures 3 and 4, respectively. Note that during the 1983 – 1991, 1995 – 2000, and 2003 – 2008 periods observer tows were not recorded because either an observer was not onboard a vessel or sharks were not identified to species. Most of the observer effort (52%) was made in 2009 and about 72% of the effort post 1989 (TED operation) is from 2009. A summary of shrimp trawl effort (nets-per-boat, boat-hours, and net-hours) is provided in Table 2 and a plot of the cumulative effort (net-hours) by year is shown in Figure 5.

The negative binomial distribution can be difficult to optimize because the response surface is flat for parameter values not close to optimal (the problem is said to be “stiff”) which results in large steps in trial parameter values that may cause numerical problems. For example, the large number of tows without a blacknose shark implies a dispersal coefficient $r << 1$; however, negative values in r will generate an error. A strategy to deal with this problem is to restrict or bound the parameter values. We used $\log_e(r)$ for the fundamental parameter instead of r directly which ensures $r > 0$. Furthermore, broad bounds were placed on all parameter values. Different initial or starting values were tried within these bounds and the same minimum for the objective function was found regardless of alternative initial values.

Comparison between the WinBUGS and ADMB programs (validation runs) for the estimation of blacknose shark bycatch estimates by year are plotted in Figure 6 from Gazey et al (2009). For comparison, the model with a year but no TED effect applied to the current data set over the 1972-2005 period is superimposed on Figure 6. With the exception of 2004 from Nichols (2007), there is good agreement regardless of program or data series. Recently, a single research tow of 23 minutes in 2004 that reported 11 blacknose sharks captured was corrected to one shark captured. Figure 7 compares the bycatch estimates using the year without a TED effect model based on 1972-2005 data (as drawn in Figure 6) to the estimates based on the 1972-2009 data. Note that the additional data (2006-09) results in lower bycatch estimates.

Parameter estimates and the associated SDs for the six alternative models (with and without year, pre-post 1990 time trends, and TED effects) are listed in Table 3. Model comparisons using AIC are provided in Table 4. The criteria selected the pre-post 1990 time trends with a TED model as the best fit to the catch rate data. This model accounts for about 99% of the AIC weighting. The year effect adds almost nothing to fitting the data, i.e., the models with a year effect are less than 1 in a 150 million as likely as the time trend models.

Blacknose shark bycatch estimates and the associated SDs by year for the alternative models are listed in Table 5. Plots of the bycatch by year for the models with a year effect are provided by Figure 8, without a year effect by Figure 9 and with the pre-post 1990 time trends in Figure 10. Note that the TED effect increases the bycatch in comparison to the without TED model for the years when TEDs were not used (1972 – 1989) and decreases the bycatch for the years when TEDs were used (1990 – 2009). Shrimp trawl effort (million net-hours) is overlaid in Figure 9 to illustrate that the bycatch estimates are directly proportional to shrimp trawl effort when the model does not contain a year effect. Also, note that the post 1990 bycatch estimates are similar for the without year and time trend models.

DISCUSSION

The models with a full year effect were shown here and by Raborn et al. (2009) and Gazey et al. (2009) to be highly over-parameterized for the blacknose shark catch rate data. Alterative models removed the year effect entirely and a less severe option used log-linear time trends pre-post 1990. These year effect modifications provided substantially better fits to the data. Also consistent with the other studies, models with TED effects were shown to fit the catch rate data better and to reduce blacknose shark bycatch estimates. However, the catch reduction estimated here was only 41%, based primarily on the 2009 observer data, in contrast to 53% estimated by Gazey et al. (2009).

The best assessed model is the pre-post 1990 time trend with a TED effect. Figure 11 plots the bycatch estimates and associated standard deviation over the 1972-2009 time periods. Note that there is a great deal of uncertainty in the estimates (the coefficient of variation exceeds 25% in all years). There remains a critical need for additional observer data to be collected concurrent with research data.

If observer tows continue to identify blacknose shark in the future as in 2009, then the structure of the estimation model will require review. For example, perhaps individual year effects devoted to 2009 and future years will provide a better fit to the data than the models applied here.

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Table 1. Elementary statistics for the catch rate data.

Data Source	Hours Towed	Number of Tows	Number of Tows with blacknose	Blacknose Caught
Research	9,462.0	28,852	131	192
Observer				
Historical (1972-82)	11,627.1	1,736	11	68.0
Characterization (1992-94)	7,366.8	1,335	11	13.0
Modern (2001-2002)	1,172.8	303	0	0.0
Modern (2009)	21,814.0	3,373	15	65.3
Total	51,442.7	35,599	168	338.3

Table 2. Shrimp trawl effort by year (millions of boat-hours and net-hours) in the Gulf of Mexico.

Year	Nets·Boat^{-1}	SD(Nets·Boat^{-1})	Boat-hours (millions)	SD(Boat-hrs)	Net-hours (millions)	SD(Net-hrs)
1972	1.870	0.076	3.773	0.010	7.054	0.289
1973	1.882	0.076	3.506	0.012	6.599	0.268
1974	1.873	0.081	3.514	0.011	6.582	0.285
1975	1.884	0.086	3.084	0.008	5.812	0.266
1976	1.955	0.112	3.707	0.013	7.247	0.418
1977	2.141	0.130	3.991	0.015	8.546	0.518
1978	2.263	0.156	4.848	0.026	10.972	0.760
1979	2.373	0.187	5.076	0.040	12.044	0.952
1980	2.436	0.213	3.462	0.021	8.432	0.740
1981	2.471	0.238	4.241	0.009	10.482	1.008
1982	2.489	0.250	4.173	0.010	10.388	1.044
1983	2.460	0.247	4.111	0.014	10.115	1.014
1984	2.425	0.267	4.602	0.014	11.160	1.230
1985	2.423	0.265	4.719	0.012	11.433	1.250
1986	2.416	0.263	5.443	0.015	13.148	1.433
1987	2.507	0.252	5.806	0.019	14.553	1.465
1988	2.521	0.258	4.939	0.016	12.451	1.274
1989	2.549	0.231	5.308	0.020	13.527	1.228
1990	2.611	0.258	5.085	0.019	13.277	1.315
1991	2.767	0.242	5.361	0.019	14.832	1.301
1992	2.670	0.218	5.200	0.019	13.885	1.135
1993	2.668	0.231	4.908	0.019	13.091	1.133
1994	2.668	0.237	4.698	0.023	12.534	1.117
1995	2.847	0.236	4.238	0.015	12.067	1.002
1996	2.961	0.224	4.552	0.016	13.475	1.021
1997	2.954	0.211	4.990	0.017	14.742	1.055
1998	2.838	0.122	5.208	0.020	14.781	0.636
1999	2.973	0.224	4.811	0.018	14.304	1.078
2000	2.994	0.246	4.610	0.017	13.801	1.135
2001	2.991	0.221	4.743	0.020	14.186	1.051
2002	3.100	0.165	4.959	0.024	15.375	0.823
2003	3.100	0.232	4.035	0.015	12.509	0.938
2004	3.100	0.267	3.519	0.012	10.909	0.941
2005	3.100	0.316	2.468	0.009	7.651	0.781
2006	3.100	0.316	2.217	0.007	6.873	0.701
2007	3.100	0.316	1.938	0.006	6.007	0.613
2008	3.100	0.316	1.507	0.015	4.672	0.479
2009	3.100	0.316	1.795	0.004	5.563	0.568

Table 3. Parameter estimates and associated standard deviation by model (parameters defined in Gazey et al. 2009, Table 1).

	Year & No TED		Year & TED		No Year & No TED		No Year & TED		Time Trnd & No TED		Time Trnd & TED	
Parameter	Est.	SD	Est.	SD	Est.	SD	Est.	SD	Est.	SD	Est.	SD
$\log_e(r)$	-4.772	0.131	-4.747	0.133	-5.083	0.127	-5.057	0.128	-5.056	0.126	-4.966	0.129
μ	-0.129	0.907	-0.215	0.904	-0.060	0.906	-0.131	0.903	0.026	0.907	-0.097	0.905
p_1									-0.105	0.035	-0.094	0.036
p_2									-0.007	0.010	0.012	0.011
y_1	0.044	0.660	0.016	0.657								
y_2	0.472	0.507	0.444	0.505								
y_3	-0.774	0.533	-0.764	0.532								
y_4	0.774	0.398	0.645	0.407								
y_5	0.039	0.477	-0.042	0.479								
y_6	1.451	0.378	1.224	0.403								
y_7	0.511	0.469	0.326	0.487								
y_8	-0.802	0.775	-0.812	0.773								
y_9	-0.873	0.588	-0.992	0.595								
y_{10}	-0.368	0.566	-0.456	0.571								
y_{11}	-0.883	0.639	-0.922	0.637								
y_{12}	-0.691	0.663	-0.716	0.660								
y_{13}	-1.173	0.711	-1.193	0.708								
y_{14}	-0.860	0.776	-0.870	0.773								
y_{15}	-0.235	0.746	-0.233	0.745								
y_{16}	-0.869	0.798	-0.864	0.797								
y_{17}	-0.885	0.796	-0.880	0.795								
y_{18}	0.015	0.626	0.031	0.624								
y_{19}	-0.331	0.665	-0.330	0.664								
y_{20}	-0.013	0.586	-0.013	0.584								
y_{21}	0.086	0.495	0.256	0.506								
y_{22}	-0.381	0.499	-0.267	0.503								
y_{23}	-0.101	0.528	0.016	0.530								
y_{24}	0.345	0.580	0.339	0.579								
y_{25}	-0.045	0.610	-0.041	0.609								
y_{26}	0.563	0.533	0.584	0.531								
y_{27}	-0.192	0.639	-0.188	0.637								
y_{28}	-0.140	0.628	-0.140	0.626								
y_{29}	0.074	0.606	0.085	0.605								
y_{30}	0.384	0.639	0.405	0.641								
y_{31}	-0.424	0.595	-0.358	0.595								
y_{32}	0.687	0.545	0.687	0.543								
y_{33}	0.298	0.601	0.326	0.599								
y_{34}	-0.209	0.741	-0.195	0.739								
y_{35}	0.060	0.663	0.077	0.662								
y_{36}	1.483	0.528	1.526	0.527								
y_{37}	1.038	0.465	1.048	0.463								
y_{38}	0.796	0.318	1.028	0.354								
s_1	-0.765	0.593	-0.707	0.595	-0.796	0.594	-0.767	0.593	-0.654	0.598	-0.497	0.598
s_2	0.066	0.578	-0.036	0.579	0.172	0.579	0.105	0.578	0.142	0.580	-0.064	0.581
s_3	-0.430	0.578	-0.471	0.577	-0.436	0.578	-0.468	0.577	-0.462	0.579	-0.536	0.578
a_1	-0.910	1.041	-1.016	1.037	-0.827	1.038	-0.921	1.033	-0.747	1.039	-0.957	1.034
a_2	-1.005	1.010	-1.109	1.007	-1.064	1.005	-1.169	1.001	-0.907	1.006	-0.950	1.004
a_3	-1.576	1.000	-1.657	0.996	-1.524	0.998	-1.561	0.994	-1.425	1.002	-1.487	0.997
a_4	-2.153	1.005	-2.292	1.001	-1.883	1.003	-2.000	0.999	-1.789	1.006	-2.088	1.004
d_1	-3.041	1.190	-3.285	1.176	-2.921	1.187	-3.141	1.173	-2.688	1.191	-3.041	1.178
d_2	-2.604	1.184	-2.788	1.171	-2.376	1.180	-2.512	1.167	-2.181	1.188	-2.441	1.174
w_1	-1.600	0.689	-0.624	0.630	-1.370	0.685	-0.531	0.614	-1.374	0.685	-0.027	0.625
w_2	0.471	0.687	-1.499	0.618	0.311	0.684	-1.241	0.592	0.400	0.685	-1.732	0.608
w_3			0.908	0.586			0.641	0.582			0.662	0.582

Table 4 . Model comparisons using Akaike information content.
AIC = Akaike Information Criteria, AIF = Akaike Information Factor.

Model	Function	Parameters	AIC	ΔAIC	AIC Weight	AIF
1. Time Trend & TED	1215.5	16	2463.0	0.0	0.989	1.000
2. Time Trend & NO TED	1221.0	15	2472.0	9.0	0.011	0.011
3. No Year & No TED	1228.3	13	2482.7	19.7	0.000	<0.001
4. No Year & TED	1227.5	14	2482.9	19.9	0.000	<0.001
5. Year & No TED	1199.4	51	2500.7	37.7	0.000	<0.001
6. Year & TED	1198.8	52	2501.5	38.5	0.000	<0.001

Table 5. Blacknose shark bycatch estimates and associated SDs by year for the alternative models.

	NMFS	WithYear Effect				No Year Effect				Trends Pre-Post 1990			
Year	Nichols (2007)	No TED	SD(No TED)	With TED	SD(With TED)	No TED	SD(No TED)	With TED	SD(With TED)	No TED	SD(No TED)	With TED	SD(With TED)
1972	14,921	14,805	10,335	24,571	18,485	25,999	5,420	42,242	15,025	34,373	10,448	69,855	26,689
1973	15,177	20,928	11,344	34,959	21,386	23,650	5,007	38,571	13,834	28,371	8,084	59,445	22,048
1974	7,743	6,014	3,435	10,444	6,782	23,401	4,899	38,131	13,615	25,347	6,694	54,073	19,366
1975	20,404	24,834	10,127	37,764	18,133	20,661	4,334	33,819	12,148	20,193	5,089	43,974	15,499
1976	13,287	14,491	7,422	22,813	13,033	25,882	5,429	41,913	14,913	22,546	5,511	47,515	16,263
1977	100,259	69,985	26,974	94,855	41,218	30,043	6,721	48,364	17,459	23,660	5,895	50,258	17,322
1978	21,472	34,936	15,420	49,102	24,078	38,110	9,339	60,868	22,631	26,856	7,201	56,419	20,113
1979	13,168	10,044	8,254	16,723	14,540	41,474	9,623	65,948	23,864	26,300	6,931	55,117	19,511
1980	8,669	6,132	3,900	9,127	6,175	26,632	6,858	41,995	15,747	15,237	4,471	32,121	12,052
1981	10,194	12,906	7,903	20,018	13,297	34,333	8,173	54,906	20,182	17,749	5,190	38,772	14,798
1982	7,963	8,041	5,541	13,083	9,671	35,617	8,492	57,070	21,023	16,509	5,130	36,504	14,511
1983	9,533	9,777	6,987	16,064	12,279	35,293	8,438	56,189	20,584	14,845	4,901	33,245	13,792
1984	7,285	6,790	5,185	11,242	9,126	39,820	9,649	63,604	23,507	15,057	5,347	34,228	14,960
1985	9,794	9,335	7,725	15,565	13,602	40,265	9,679	64,340	23,715	13,659	5,173	31,129	14,241
1986	20,222	20,003	15,880	33,923	28,743	46,466	10,943	74,505	27,338	14,156	5,696	32,788	15,744
1987	12,131	11,481	9,733	19,476	17,506	49,820	11,764	79,644	29,148	13,642	5,889	31,829	16,107
1988	10,900	9,983	8,447	16,958	15,220	44,248	10,470	70,957	26,083	10,887	5,007	25,715	13,687
1989	26,649	27,544	18,627	46,905	34,641	49,710	11,679	79,036	28,715	11,021	5,383	25,888	14,423
1990	20,081	18,342	13,110	12,815	9,601	46,781	11,269	36,475	10,129	59,887	15,007	29,903	9,162
1991	37,291	28,261	17,912	19,802	13,301	52,976	12,248	41,530	11,133	67,047	16,065	34,196	10,066
1992	38,197	30,300	15,160	25,387	12,997	50,815	11,285	40,122	10,361	64,242	14,766	34,392	9,573
1993	15,514	17,841	9,194	14,105	7,546	48,012	10,709	37,883	9,834	60,076	13,777	32,511	8,992
1994	27,351	21,490	11,377	17,001	9,255	43,784	9,801	34,478	8,986	54,643	12,525	30,019	8,194
1995	40,316	33,571	21,000	23,626	15,687	43,464	9,583	34,312	8,822	54,221	12,248	30,909	8,154
1996	35,295	23,802	15,609	17,074	11,763	45,253	9,777	35,909	9,036	56,459	12,564	33,461	8,540
1997	58,309	49,810	28,815	36,083	22,144	52,612	11,181	41,683	10,387	64,539	14,049	38,115	9,566
1998	34,082	23,379	15,855	16,682	11,861	52,254	10,608	41,313	9,985	64,133	13,478	38,961	9,347
1999	27,461	23,735	15,959	16,639	11,796	50,430	11,127	39,553	10,246	60,731	13,707	36,315	9,239
2000	31,556	28,815	18,834	20,406	14,071	49,970	11,328	39,228	10,356	59,284	13,725	35,703	9,223
2001	45,593	41,916	28,711	30,127	21,655	52,699	11,870	41,524	10,856	62,195	14,435	38,769	9,823
2002	25,400	20,419	12,600	15,375	9,872	58,891	12,677	46,433	11,735	69,016	15,442	43,518	10,646
2003	54,258	48,092	28,306	33,868	21,309	46,217	9,946	36,386	9,212	53,862	12,143	34,529	8,407
2004	65,546	28,883	18,751	21,124	14,335	40,481	9,033	32,215	8,269	46,877	11,048	31,306	7,762
2005	20,568	12,406	9,769	8,951	7,279	29,284	6,544	23,352	5,991	33,683	8,021	22,953	5,697
2006		14,231	10,108	10,137	7,527	25,477	5,767	19,993	5,280	29,038	7,111	19,554	4,996
2007		53,319	31,012	38,720	23,910	22,908	5,458	17,894	4,932	25,763	6,651	17,381	4,630
2008		26,095	13,635	18,237	10,373	17,215	4,215	13,369	3,774	19,276	5,202	13,193	3,623
2009		23,166	6,110	20,354	5,520	19,691	4,423	15,374	4,057	22,065	5,670	15,668	4,079
Mean (1990-2009)		28,394		20,826		42,461		33,451		51,352		30,568	
TED Reduction				26.7%				21.2%				40.5%	

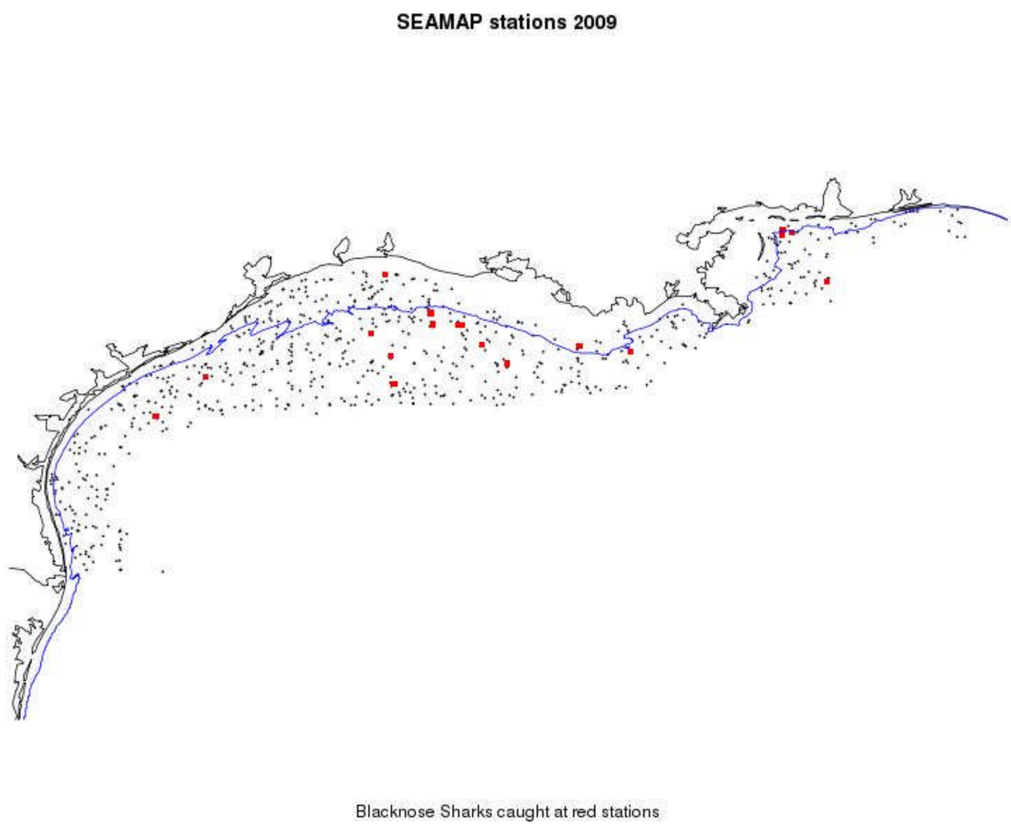

Figure 1. SEAMAP (research) sampling locations and locations where blacknose shark were caught (red).

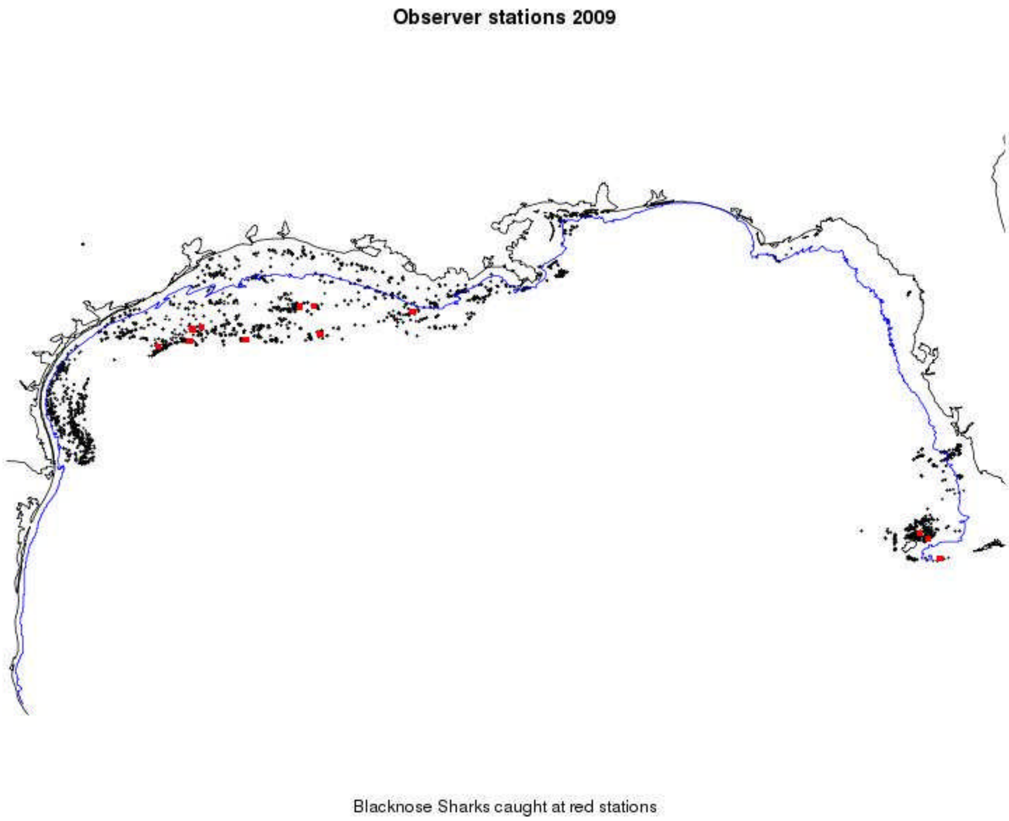

Figure 2. Observer sampling locations and locations where blacknose shark were caught (red).

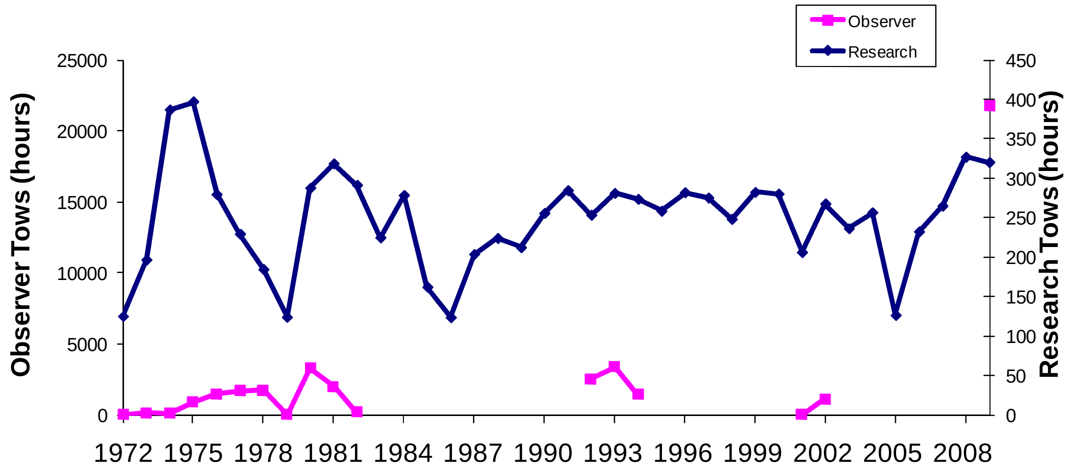

Figure 3. Total number of tow hours by year for shrimp trawls vessels with observers and with research vessels.

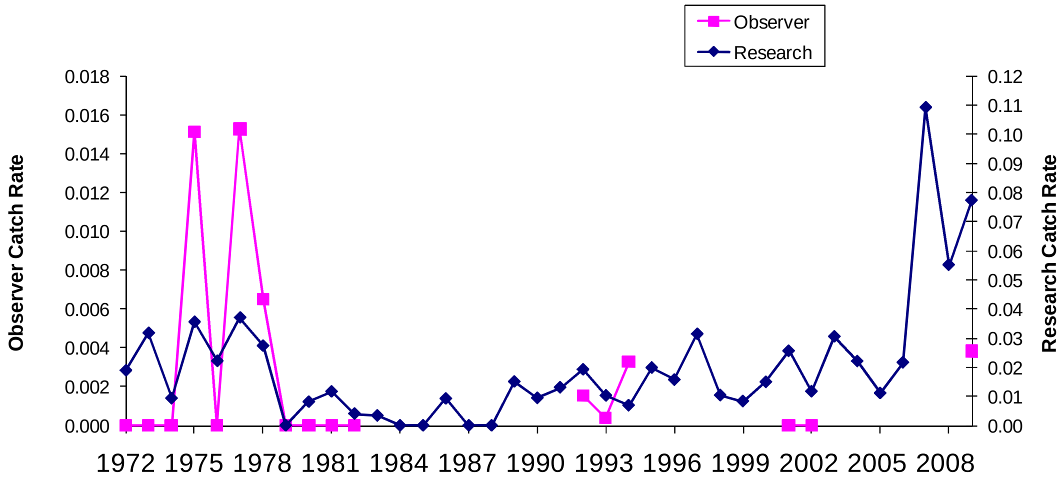

Figure 4. Observer and research blacknose shark mean catch rate by shrimp trawls by year.

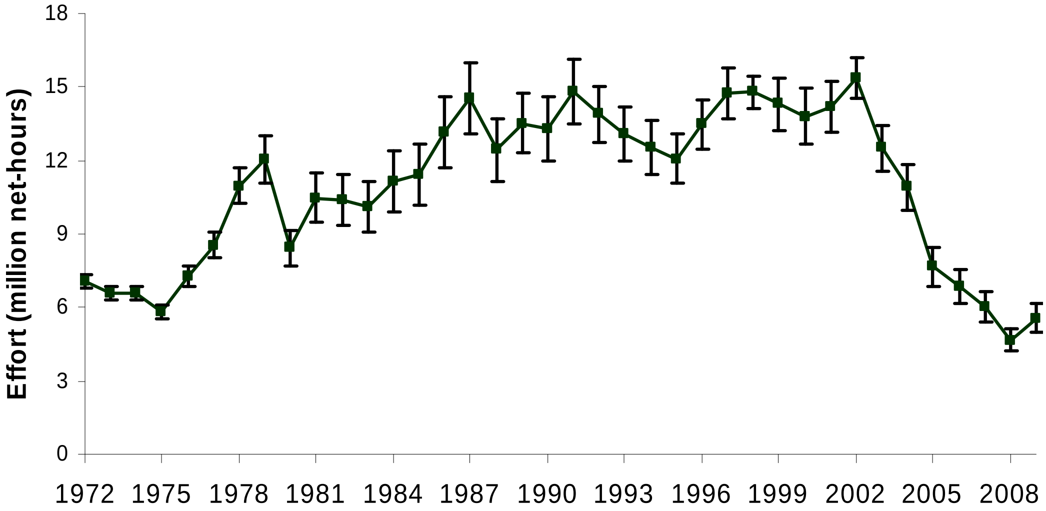

Figure 5. Shrimp trawl effort (million of net-hours) by year in the Gulf of Mexico. The error bars are plus/minus one standard deviation.

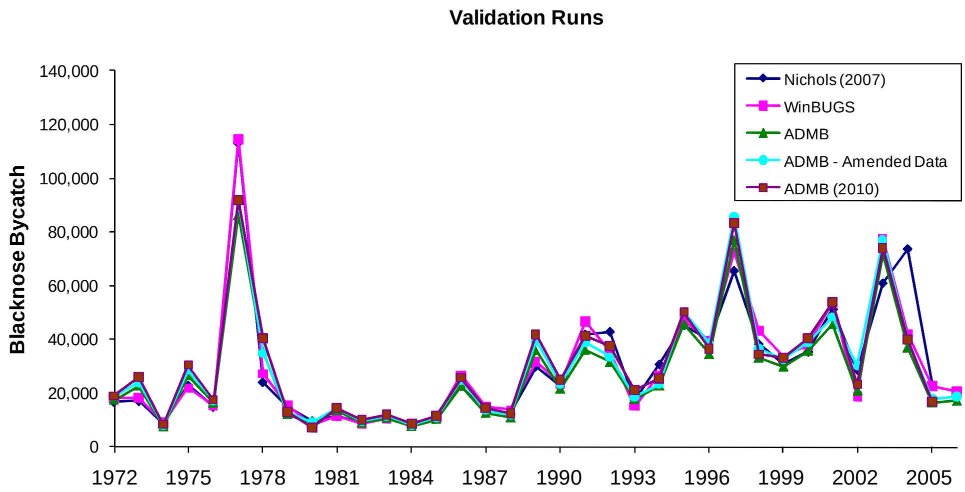

Figure 6. Blacknose shark bycatch estimation using alternative estimation programs and data. The Nichols (2007) series is the bycatch used for the SEDAR13 stock assessment. The "WinBUGS" series uses the WinBUGS program on a data series compiled to duplicate that used by Nichols (2007). The "ADMB" series uses the same data with the ADMB program and the year without a TED effects. The "ADMB – Amended" series is the data used by Gazey et al. 2009. The "ADMB (2010)" series is the data used in this document.

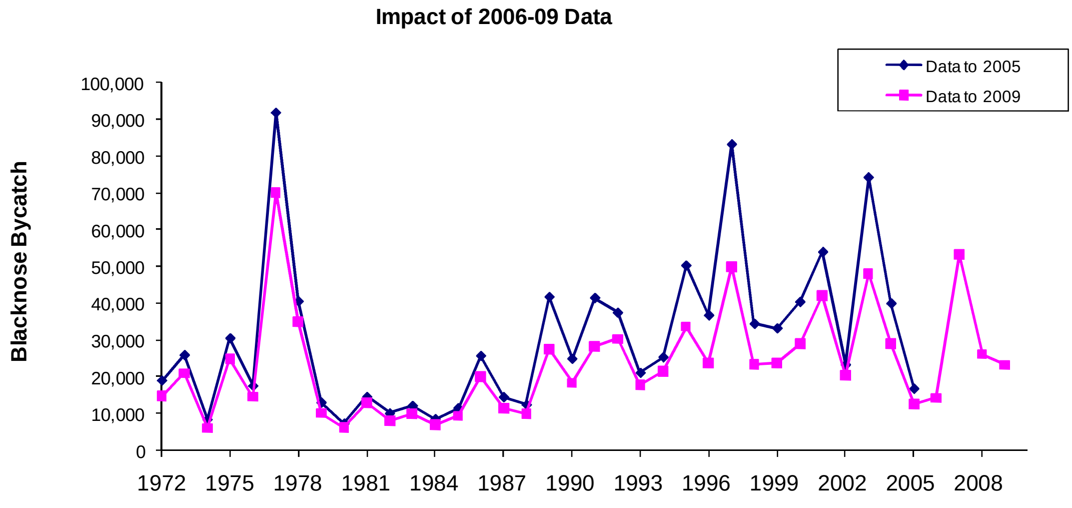

Figure 7. Blacknose bycatch estimates using the year and without TED effects based on the 1972-2005 data and on the 1972-2009 data.

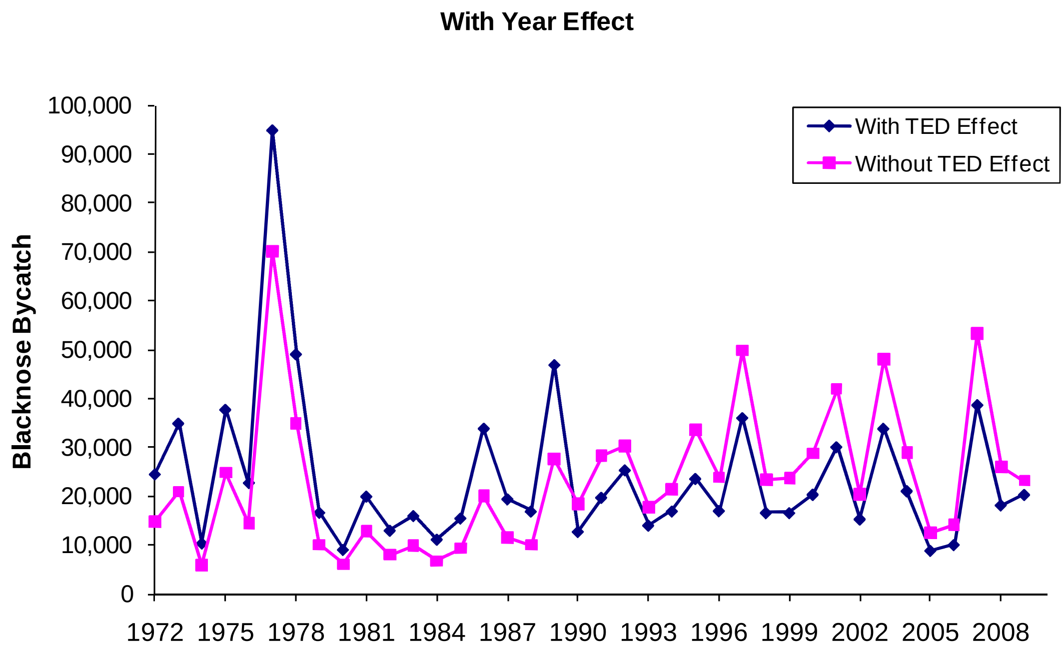

Figure 8. Blacknose shark bycatch estimates with a year effect.

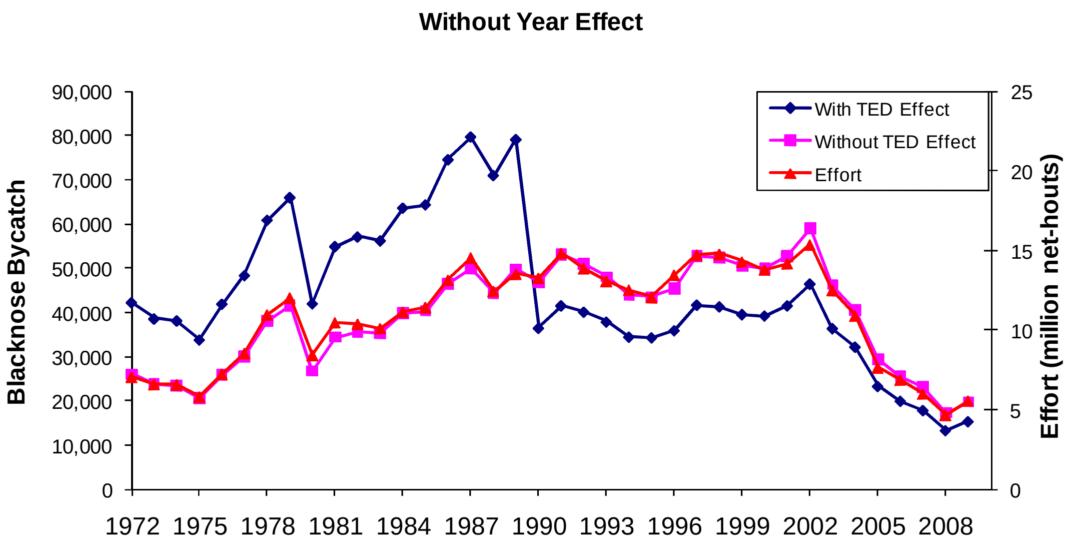

Figure 9. Blacknose shark bycatch estimates without a year effect. Annual shrimp trawl effort (million net-hours) is overlaid.

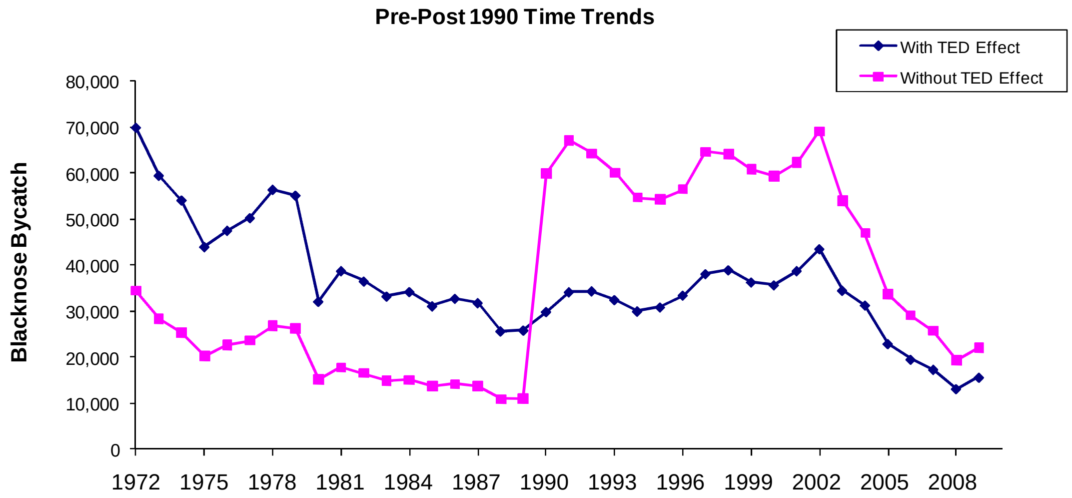

Figure 10. Blacknose shark bycatch estimates with a pre-post 1990 time trends in replacement of the year effect .

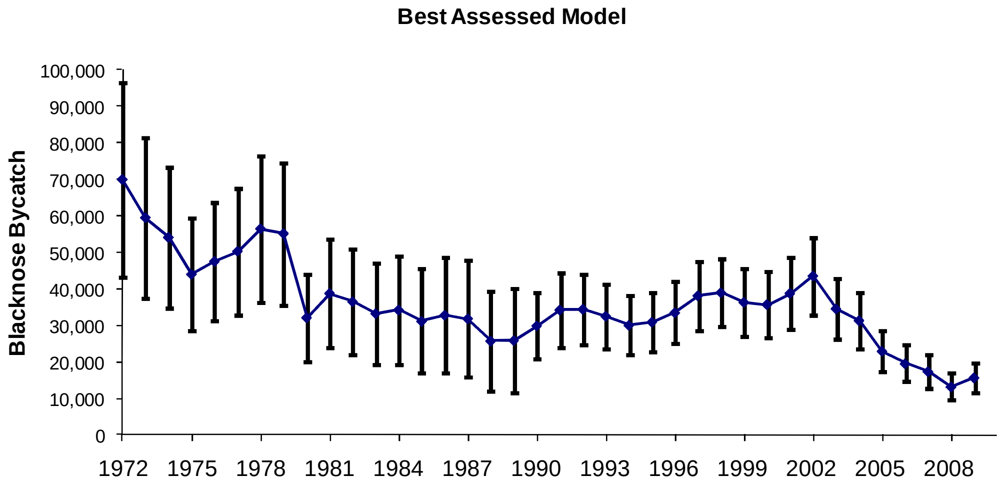

Figure 11. Best assessed model (pre-post 1990 time trends with a TED effect based on AIC) and subsequent blacknose shark bycatch estimates. The error bars represent plus/minus one standard deviation.