STANDARDIZED CATCH RATES OF SANDBAR SHARKS (*Carcharhinus plumbeus*) IN THE VIRGINIA - MASSACHUSETTS (U.S.) ROD AND REEL FISHERY DURING 1986-2004

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SUMMARY

Abundance indices for sandbar (Carcharhinus plumbeus) sharks off the coast of the United States from Virginia through Massachusetts were developed using data obtained during interviews of rod and reel anglers in 1986-2004. Subsets of the data were analyzed to assess effects of factors such as month, area fished, boat type (private or charter), interview type (dockside or phone) and fishing method on catch per unit effort. Standardized catch rates were estimated through generalized linear models by applying delta-Poisson error distribution assumptions. A stepwise approach was used to quantify the relative importance of the main factors explaining the variance in catch rates

KEYWORDS

Catch/effort, Abundance, Sport fishing, Fishery surveys, Multivariate analyses, Stock assessments, Catch rate standardization, Generalized linear model, Shark fisheries, Pelagic fisheries

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1. INTRODUCTION

Data from the United States National Marine Fisheries Service's Large Pelagic Survey have typically been used to develop abundance indices for a variety of species, including bluefin tuna (Brown 2002), sharks (Brown 2000), bigeye and yellowfin tuna (Brown 1999, Brown 2004), and sharks (Brown 2000, Brown 2004) . This paper describes the development of indices of abundance for sandbar sharks (*Carcharhinus plumbeus*) for the period 1986-2004.

2. MATERIAL AND METHODS

The Large Pelagic Survey (LPS) collects data on the catch and effort of individual fishing trips through interviews with fishermen at the dock and in some years has collected such information over the telephone. Information collected usually includes date, landing area, boat type (charter or private), fishing area, number of anglers fishing, number of lines in the water, hours fished, type of fishing (primarily trolling or chumming), fishing target, sea surface temperature (SST) and catch.

Fishing areas were defined for this analysis at two levels of detail based upon landing location, STATE and REGION. The states included (from south to north along the mid-Atlantic coast of the United States) Virginia, Maryland, Delaware, New Jersey, New York, Connecticut, Rhode Island, and Massachusetts. Considering that fishing trips in this fishery are generally of short duration (less than one day, some of two-three days), the landing state can be expected to provide a reasonable proxy for fishing area. The REGIONs were defined based upon state; they were the southern area (SOUTH) from Virginia through New Jersey and the northern area (NORTH) from New York through Massachusetts. These definitions are consistent with definitions for previous shark catch per unit effort (CPUE) standardization analyses for this fishery (Brown 2000, Brown 2004).

Observations were limited to those on which anglers indicated that they were targeting sharks and were employing the chumming fishing method exclusively. These restrictions are consistent with restrictions imposed for previous shark catch per unit effort (CPUE) standardization analyses for this fishery (Brown 2000, Brown 2004). Trips targeting other species categories (such as tunas) were not included because they were thought to be adding noise rather than information.

Factors which were considered as possible influences on catch rates included YEAR, MONTH, REGION, BOATTYPE, sea surface temperature (TEMP), STATE, MILES offshore, tournament participation (TOURNAMENT, Y=yes and N=no) and interview type (dockside/telephone recall or DOCKRECL). Preliminary analysis indicated that sandbar shark CPUE defined as fish per line*hour (number of lines X number of hours fished) was more independent of effort level than was CPUE defined as fish per hour. Therefore, line*hours was considered to be the preferred measure of fishing effort, in contrast to previous analyses of LPS catch rate data for sharks (Brown 2000, Brown 2004) where fishing effort had been defined as hours fished.

The Lo method (Lo *et al.* 1992) was used to develop standardized indices; with that method separate analyses are conducted of the positive catch rates and the proportions of the observed trips which were successful. The error distribution for the proportion positive analysis was assumed to be binomial; for the positive catch rate analyses a Poisson error distribution was assumed, fitting the number of yellowfin tuna per trip with the natural log of the fishing hours as the offset term.

A stepwise approach was used to quantify the relative importance of the main factors explaining the variance in catch rates. That is, first the Null model was run, in which no factors were entered in the model. These results reflect the distribution of the nominal data. Each potential factor was then tested one at a time. The results were then ranked from greatest to least reduction in deviance per degree of freedom when compared to the Null model. The factor which resulted in the greatest reduction in deviance per degree of freedom was then incorporated into the model, provided two conditions were met: 1) the effect of the factor was determined to be significant at at least the 5% level based upon a Chi-Square test, and 2) the deviance per degree of freedom was reduced by at least 1% from the less complex model. This process was repeated, adding factors one at a time at each step, until no factor met the criteria for incorporation into the final model. After development of the main effects model, two-way interactions between factors were tested for inclusion for in the model.

The relative indices of abundance by year are determined based upon the standardized year effects. The product of the standardized proportion positives and the standardized positive catch rates was used to calculate overall standardized catch rates.

3. RESULTS AND DISCUSSION

The nominal catch rate trend is shown in **Table 1** and included in **Figure 1**. The stepwise construction of the standardization model is shown in **Table 2** for the proportion positive analysis and in **Table 3** for the positive catch rate analysis. The final model for the proportion positive analysis includes the factors YEAR and TEMP. For the positive catch rate analysis, the final model includes the factors YEAR, MONTH, and STATE. No two-way interactions, including year interactions, were found to be significant in either proportion positive or positive analyses.

The results of the relative abundance analyses for sandbar sharks in the Virginia - Massachusetts rod and reel fishery (1986-2004) are shown in **Table 4** (proportion positive) and in **Table 5** (positive catch trips). The final models and index trend are shown in **Table 6** and **Figure 1**.

The large uncertainty in the standardized CPUE estimates, while due in part to the low numbers of shark targeted trips using chumming/chunking within the LPS data, are likely primarily due to the relative infrequency of sandbar shark catches. The uncertainties around estimates for more commonly caught sharks, such as unclassified mako (*Isurus sp.*), dusky (*Carcharhinus obscurus*), and blue (*Prionace glauca*) sharks, have tended to be much smaller in previous analyses (Brown 2000, Brown 2004), while those for sandbar sharks have been consistently large.

4. REFERENCES

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Table 1. Nominal Catch Rates
(fish per 1000 line*hours)
for SANDBAR SHARKS

YEAR	Catch Rate	CV	Number of Observations
1986	14.94	3.68	502
1987	3.60	5.34	741
1988	12.92	3.09	388
1989	16.02	2.81	583
1990	5.54	4.91	807
1991	8.77	7.04	784
1992	5.25	4.26	731
1993	2.24	14.87	411
1994	1.90	6.00	313
1995	2.04	13.42	360
1996	1.77	6.92	177
1997	3.37	9.38	275
1998	0.68	8.05	119
1999	0.87	8.13	110
2000	0.66	10.71	207
2001	8.48	7.66	131
2002	1.37	8.00	156
2003	0.85	13.92	541
2004	0.28	11.29	552

Table 2. Results of the stepwise procedure to develop the proportion positive catch rate model for sandbar sharks (*Carcharhinus plumbeus*).

There are no explanatory factors in the base model.

FACTOR	DEGF	DEVIANCE	DEV/DF	%REDUCTION	LOGLIKE	CHISQ	PROBCHISQ
BASE	7887	3864.7	0.4900		-1932.4		
YEAR	7869	3468.9	0.4408	10.04	-1734.5	395.80	0.00000
TEMP	7886	3755.1	0.4762	2.82	-1877.6	109.57	0.00000
TEMP*TEMP	7886	3757.2	0.4764	2.77	-1878.6	107.49	0.00000
STATE	7880	3812.0	0.4838	1.28	-1906.0	52.70	0.00000
MONTH	7884	3832.9	0.4862	0.78	-1916.5	31.79	0.00000
DOCKRECL	7886	3850.6	0.4883	0.35	-1925.3	14.11	0.00017
REGION	7886	3858.8	0.4893	0.14	-1929.4	5.91	0.01508
BOATTYPE	7886	3862.3	0.4898	0.05	-1931.1	2.46	0.11701
TOURNAMENT	7886	3862.9	0.4898	0.04	-1931.4	1.86	0.17276

The explanatory factors in the base model are: YEAR

FACTOR	DEGF	DEVIANCE	DEV/DF	%REDUCTION	LOGLIKE	CHISQ	PROBCHISQ
BASE	7869	3468.9	0.4408		-1734.5		
TEMP	7868	3405.0	0.4328	1.83	-1702.5	63.89	0.00000
TEMP*TEMP	7868	3405.2	0.4328	1.82	-1702.6	63.67	0.00000
STATE	7862	3431.4	0.4365	0.99	-1715.7	37.53	0.00000
MONTH	7866	3444.6	0.4379	0.66	-1722.3	24.27	0.00002
TOURNAMENT	7868	3463.1	0.4401	0.16	-1731.5	5.85	0.01557
REGION	7868	3464.7	0.4404	0.11	-1732.3	4.22	0.03992
BOATTYPE	7868	3465.7	0.4405	0.08	-1732.8	3.25	0.07146
DOCKRECL	7868	3468.1	0.4408	0.01	-1734.1	0.80	0.37052

The explanatory factors in the base model are: YEAR TEMP

FACTOR	DEGF	DEVIANCE	DEV/DF	%REDUCTION	LOGLIKE	CHISQ	PROBCHISQ
BASE	7868	3405.0	0.4328		-1702.5		
STATE	7861	3375.4	0.4294	0.78	-1687.7	29.66	0.00011
MONTH	7865	3397.5	0.4320	0.18	-1698.8	7.49	0.05774
BOATTYPE	7867	3403.3	0.4326	0.04	-1701.6	1.76	0.18479
TOURNAMENT	7867	3403.5	0.4326	0.03	-1701.7	1.57	0.20993
DOCKRECL	7867	3404.6	0.4328	-0.00	-1702.3	0.42	0.51661
REGION	7867	3404.7	0.4328	-0.00	-1702.3	0.34	0.56052
TEMP*TEMP	7867	3405.0	0.4328	-0.01	-1702.5	0.00	0.99272

FINAL MODEL: SUCCESS=YEAR+TEMP (sea surface temperature)
%REDUCTION: percent difference in deviance/df between the newly included factor and the previous factor entered into the model; LOGLIKE: log likelihood; CHISQ: Pearson Chi-square statistic; PROBCHISQ: significance level of the Chi-square statistic.

Table 3. Results of the stepwise procedure to develop the positive catch rate model for sandbar sharks (*Carcharhinus plumbeus*).

There are no explanatory factors in the base model.

FACTOR	DEGF	DEVIANCE	DEV/DF	%REDUCTION	LOGLIKE	CHISQ	PROBCHISQ
BASE		677	742.8	1.0972		-642.0	
YEAR	659	688.0	1.0440	4.85	-614.6	54.82	0.00001
MONTH	674	717.0	1.0638	3.05	-629.1	25.83	0.00001
DOCKRECL	676	731.4	1.0820	1.38	-636.4	11.36	0.00075
TOURNAMENT	676	731.5	1.0820	1.38	-636.4	11.34	0.00076
STATE	671	728.5	1.0857	1.05	-634.9	14.29	0.02660
REGION	676	739.2	1.0935	0.34	-640.2	3.60	0.05780
BOATTYPE	676	742.6	1.0985	-0.12	-641.9	0.24	0.62404

The explanatory factors in the base model are: YEAR

FACTOR	DEGF	DEVIANCE	DEV/DF	%REDUCTION	LOGLIKE	CHISQ	PROBCHISQ
BASE	659	688.0	1.0440		-614.6		
MONTH	656	667.0	1.0168	2.60	-604.2	20.93	0.00011
STATE	653	673.4	1.0313	1.21	-607.3	14.54	0.02414
DOCKRECL	658	680.1	1.0335	1.00	-610.7	7.93	0.00486
TOURNAMENT	658	680.1	1.0336	1.00	-610.7	7.88	0.00499
BOATTYPE	658	686.8	1.0438	0.02	-614.0	1.17	0.27953
REGION	658	686.9	1.0440	0.00	-614.1	1.04	0.30672

The explanatory factors in the base model are: YEAR MONTH

FACTOR	DEGF	DEVIANCE	DEV/DF	%REDUCTION	LOGLIKE	CHISQ	PROBCHISQ
BASE	656	667.0	1.0168		-604.2		
STATE	650	650.9	1.0014	1.52	-596.1	16.12	0.01315
DOCKRECL	655	661.8	1.0103	0.64	-601.5	5.29	0.02145
TOURNAMENT	655	663.9	1.0136	0.32	-602.6	3.14	0.07627
BOATTYPE	655	664.6	1.0147	0.21	-602.9	2.45	0.11770
REGION	655	666.9	1.0181	-0.13	-604.1	0.18	0.67440

The explanatory factors in the base model are: YEAR MONTH STATE

FACTOR	DEGF	DEVIANCE	DEV/DF	%REDUCTION	LOGLIKE	CHISQ	PROBCHISQ
BASE	650	650.9	1.0014		-596.1		
TOURNAMENT	649	645.2	0.9941	0.73	-593.2	5.76	0.01644
DOCKRECL	649	646.7	0.9965	0.49	-594.0	4.19	0.04065
REGION	650	650.9	1.0014	0.00	-596.1	0.00	.
BOATTYPE	649	650.6	1.0024	-0.10	-595.9	0.35	0.55237

FINAL MODEL: Sandbar Sharks (Kept+Released) =YEAR+MONTH+STATE

%REDUCTION: percent difference in deviance/df between the newly included factor and the previous factor entered into the model; LOGLIKE: log likelihood; CHISQ: Pearson Chi-square statistic; PROBCHISQ: significance level of the Chi-square statistic.

Table 4. Results of the sandbar sharks (*Carcharhinus plumbeus*) analysis (1986-2004).
Lo method with binomial error assumption for proportion positives.

Class Level Information

Class	Levels	Values
YEAR	19	1986 1987 1988 1989 1990 1991 1992 1993 1994 1995 1996 1997 1998 1999 2000 2001 2002 2003 2004

Response Profile

Ordered Value	success	Total Frequency
1	1	526
2	0	7362

PROC GENMOD is modeling the probability that success='1'.

Criteria For Assessing Goodness Of Fit

Criterion	DF	Value	Value/DF
Deviance	7868	3405.0237	0.4328
Scaled Deviance	7868	3405.0237	0.4328
Pearson Chi-Square	7868	8096.8260	1.0291
Scaled Pearson X2	7868	8096.8260	1.0291
Log Likelihood		-1702.5119	

Analysis Of Parameter Estimates

Parameter		DF	Estimate	Standard Error	Wald 95% Confidence Limits		Chi-Square	Pr > ChiSq
Intercept		1	-9.9601	0.8041	-11.5361	-8.3841	153.43	<.0001
YEAR	1986	1	3.1094	0.5180	2.0942	4.1246	36.04	<.0001
YEAR	1987	1	1.9373	0.5312	0.8962	2.9784	13.30	0.0003
YEAR	1988	1	3.0246	0.5235	1.9985	4.0506	33.38	<.0001
YEAR	1989	1	3.3770	0.5130	2.3715	4.3825	43.33	<.0001
YEAR	1990	1	2.3951	0.5182	1.3796	3.4107	21.37	<.0001
YEAR	1991	1	2.3328	0.5200	1.3137	3.3519	20.13	<.0001
YEAR	1992	1	2.6385	0.5197	1.6198	3.6572	25.77	<.0001
YEAR	1993	1	1.7267	0.6371	0.4780	2.9754	7.35	0.0067
YEAR	1994	1	1.4546	0.5890	0.3001	2.6091	6.10	0.0135
YEAR	1995	1	0.4982	0.7108	-0.8949	1.8913	0.49	0.4834
YEAR	1996	1	1.3007	0.6777	-0.0275	2.6289	3.68	0.0549
YEAR	1997	1	1.4703	0.6061	0.2824	2.6583	5.89	0.0153
YEAR	1998	1	0.6477	0.8731	-1.0635	2.3589	0.55	0.4582
YEAR	1999	1	0.8903	0.8731	-0.8209	2.6015	1.04	0.3079
YEAR	2000	1	0.3458	0.8704	-1.3601	2.0516	0.16	0.6912
YEAR	2001	1	0.9411	0.7709	-0.5699	2.4521	1.49	0.2222
YEAR	2002	1	0.8733	0.7698	-0.6356	2.3822	1.29	0.2566
YEAR	2003	1	0.1993	0.6740	-1.1216	1.5202	0.09	0.7674
YEAR	2004	0	0.0000	0.0000	0.0000	0.0000	.	.
TEMP		1	0.0750	0.0093	0.0568	0.0932	65.13	<.0001
Scale		0	1.0000	0.0000	1.0000	1.0000		

NOTE: The scale parameter was held fixed.

LR Statistics For Type 3 Analysis

Source	DF	Chi-Square	Pr > ChiSq
YEAR	18	350.12	<.0001
TEMP	1	63.89	<.0001

Table 5. Results of the sandbar sharks (*Carcharhinus plumbeus*) analysis (1986-2004). Lo method with Poisson error assumption for positive catch trips

Class Level Information

Class	Levels	Values
YEAR	19	1986 1987 1988 1989 1990 1991 1992 1993 1994 1995 1996 1997 1998 1999 2000 2001 2002 2003 2004
MONTH	4	6 7 8 9
STATE	7	CT DE MD NJ NY RI VA

Criteria For Assessing Goodness Of Fit

Criterion	DF	Value	Value/DF
Deviance	650	650.9296	1.0014
Scaled Deviance	650	650.9296	1.0014
Pearson Chi-Square	650	1134.3504	1.7452
Scaled Pearson X2	650	1134.3504	1.7452
Log Likelihood		-596.0944	

Analysis Of Parameter Estimates

Parameter		DF	Estimate	Standard Error	Wald 95% Confidence Limits		Chi-Square	Pr > ChiSq
Intercept		1	-3.1263	0.4563	-4.0205	-2.2321	46.95	<.0001
YEAR	1986	1	0.4394	0.3770	-0.2995	1.1782	1.36	0.2438
YEAR	1987	1	0.2884	0.3829	-0.4620	1.0388	0.57	0.4513
YEAR	1988	1	0.4132	0.3910	-0.3531	1.1795	1.12	0.2906
YEAR	1989	1	0.2734	0.3788	-0.4691	1.0159	0.52	0.4705
YEAR	1990	1	0.0241	0.3883	-0.7370	0.7851	0.00	0.9506
YEAR	1991	1	0.5945	0.3846	-0.1594	1.3484	2.39	0.1222
YEAR	1992	1	0.0747	0.3861	-0.6821	0.8315	0.04	0.8466
YEAR	1993	1	0.3170	0.4894	-0.6422	1.2762	0.42	0.5171
YEAR	1994	1	0.0365	0.4657	-0.8762	0.9492	0.01	0.9375
YEAR	1995	1	0.8729	0.4381	0.0142	1.7317	3.97	0.0463
YEAR	1996	1	0.3192	0.4858	-0.6330	1.2714	0.43	0.5111
YEAR	1997	1	0.2537	0.4516	-0.6315	1.1388	0.32	0.5743
YEAR	1998	1	-0.2035	0.8047	-1.7808	1.3738	0.06	0.8004
YEAR	1999	1	0.1354	0.6002	-1.0410	1.3119	0.05	0.8215
YEAR	2000	1	0.6404	0.6305	-0.5953	1.8762	1.03	0.3097
YEAR	2001	1	1.5659	0.4495	0.6849	2.4470	12.13	0.0005
YEAR	2002	1	0.4077	0.5846	-0.7381	1.5536	0.49	0.4856
YEAR	2003	1	0.4615	0.4828	-0.4848	1.4078	0.91	0.3391
YEAR	2004	0	0.0000	0.0000	0.0000	0.0000	.	.
MONTH	6	1	-0.3157	0.1873	-0.6827	0.0513	2.84	0.0918
MONTH	7	1	-0.2842	0.1862	-0.6492	0.0809	2.33	0.1271
MONTH	8	1	0.1059	0.1946	-0.2754	0.4873	0.30	0.5861
MONTH	9	0	0.0000	0.0000	0.0000	0.0000	.	.
STATE	CT	1	0.5033	0.3640	-0.2101	1.2167	1.91	0.1667
STATE	DE	1	0.0922	0.3192	-0.5334	0.7178	0.08	0.7727
STATE	MD	1	0.1274	0.3185	-0.4968	0.7516	0.16	0.6891
STATE	NJ	1	0.5028	0.2983	-0.0819	1.0874	2.84	0.0919
STATE	NY	1	0.3889	0.2974	-0.1940	0.9719	1.71	0.1910
STATE	RI	1	0.5245	0.3162	-0.0953	1.1443	2.75	0.0972
STATE	VA	0	0.0000	0.0000	0.0000	0.0000	.	.
Scale		0	1.0000	0.0000	1.0000	1.0000		

NOTE: The scale parameter was held fixed.

LR Statistics For Type 3 Analysis

Source	DF	Chi-Square	Pr > ChiSq
YEAR	18	53.53	<.0001
MONTH	3	22.51	<.0001
STATE	6	16.12	0.0131

Table 5. Relative Abundance Indices for SANDBAR SHARKS (including 95% confidence intervals) Proportion Positive err. dist: binomial Positive err. dist: Poisson				
YEAR	**INDEX**	**LCI**	**UCI**	**CV**
1986	2.992	1.517	4.467	0.251
1987	0.877	-0.119	1.874	0.580
1988	2.707	0.825	4.589	0.355
1989	3.183	1.884	4.483	0.208
1990	1.037	0.106	1.968	0.458
1991	1.731	0.522	2.940	0.356
1992	1.366	0.252	2.479	0.416
1993	0.737	-1.701	3.176	1.687
1994	0.428	-1.081	1.937	1.799
1995	0.386	-1.313	2.086	2.244
1996	0.489	-1.613	2.591	2.193
1997	0.540	-1.200	2.281	1.644
1998	0.153	-2.007	2.313	7.218
1999	0.272	-2.089	2.633	4.426
2000	0.263	-2.159	2.686	4.692
2001	1.196	-2.462	4.854	1.560
2002	0.351	-2.029	2.731	3.456
2003	0.190	-1.077	1.458	3.394
2004	0.099	-0.947	1.144	5.414

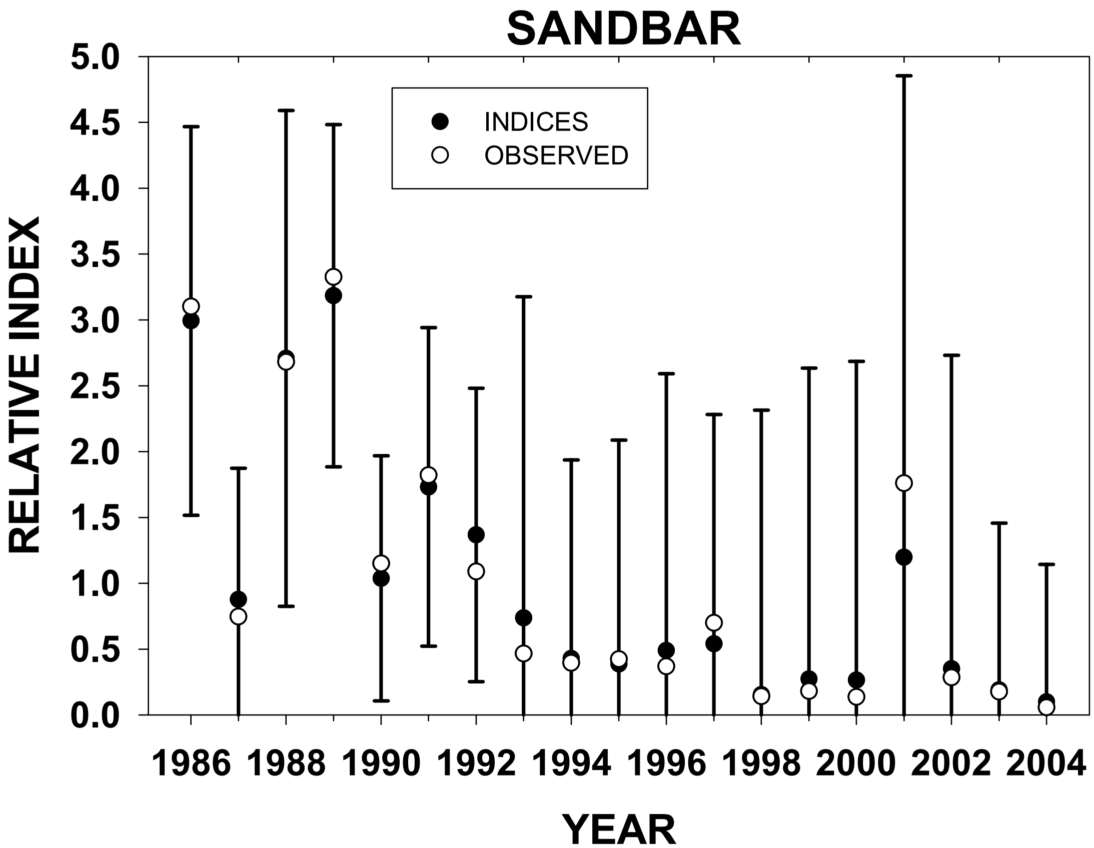
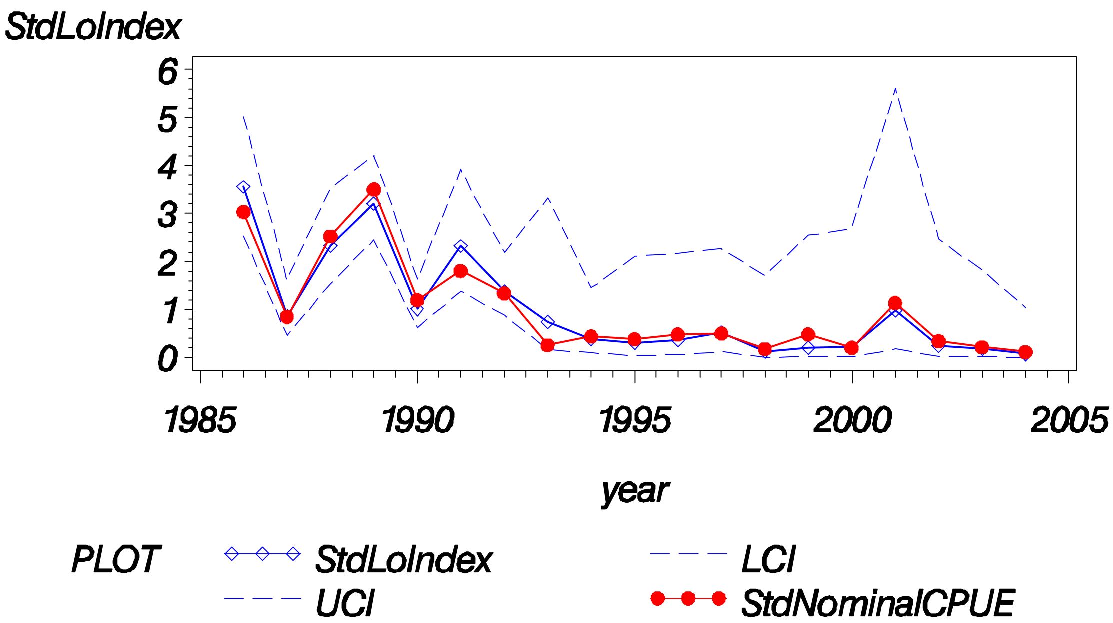


Figure 1. Relative abundance indices for SANDBAR SHARKS with approximate 95% confidence intervals.
(Proportion Positive error distribution: binomial; Positive error distribution: Poisson)
Model = **YEAR+TEMP** (for proportion positive)
Model = **YEAR+MONTH +STATE** (for positive catches)

Zero-inflated delta-negative-binomial for sandbar
Index Output
Walter Ingram and Craig Brown



StdLoIndex	SurveyYear	Frequency	N	CV	LCL	UCL
3.55741	1986	0.14542	502	0.17300	2.52333	5.01526
0.85879	1987	0.04723	741	0.32277	0.45757	1.61185
2.32620	1988	0.13918	388	0.20938	1.53719	3.52018
3.20366	1989	0.20240	583	0.13590	2.44424	4.19902
1.00836	1990	0.08426	807	0.24737	0.61935	1.64169
2.32659	1991	0.07653	784	0.26411	1.38411	3.91083
1.38158	1992	0.08345	731	0.23308	0.87217	2.18852
0.73934	1993	0.01703	411	0.87179	0.16435	3.32597
0.37834	1994	0.03514	313	0.75472	0.09878	1.44904
0.30158	1995	0.01111	360	1.25456	0.04314	2.10845
0.36946	1996	0.02825	177	1.09169	0.06283	2.17273
0.52979	1997	0.03273	275	0.83369	0.12392	2.26504
0.12446	1998	0.01681	119	2.13849	0.00905	1.71196
0.20196	1999	0.01818	110	1.99444	0.01603	2.54490
0.21345	2000	0.00966	207	1.98954	0.01699	2.68134
0.98561	2001	0.02290	131	1.06439	0.17288	5.61917
0.23588	2002	0.01923	156	1.72076	0.02257	2.46466
0.18145	2003	0.00924	541	1.66296	0.01814	1.81507
0.07610	2004	0.00725	552	2.13568	0.00554	1.04508

Due to large CV's, the data were redeveloped using a zero-inflated, delta-negative-binomial approach. The variables that were significant for each sub-model in the above document were also significant in these new indices (i.e., for the zero-inflated binomial sub-model: temperature and year; and for the negative binomial sub-model: year, state and month). Separate covariance matrices were computed for each year within each sub-model, and asymmetric confidence intervals were developed for index estimates. CV's were much lower for this time series than the previous, but are still large for later years as CPUE estimates decline.