Standardized catch rates of sandbar, dusky and blacknose sharks from the Shark Fishery Bottom Longline Observer Program, 1994-2009

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Abstract

Catch rate series were developed from the data collected by on-boards observers in the shark bottom longline fishery for the period 1994-2009 for sandbar, dusky, and blacknose shark. All series were subjected to a Generalized Linear Model (GLM) standardization technique that treats separately the proportion of sets with positive catches (i.e., where at least one shark was caught) assuming a binomial error distribution with a logit link function, and the catch rates of sets with positive catches assuming a lognormal error distribution with a log link function. Because observations of the fishery have been conducted using two different non- overlapping sampling strategies (i.e. voluntary and mandatory), catch rates were modeled independently for two time series representing periods of 1994-2001 (voluntary) and 2002-2009 (mandatory). In addition to spatio-temporal factors, a factor reflecting the addition of a special sandbar shark fishery was added to the mandatory series. Year, depth and time were significant as a main effect in most models. The relative abundance index over both time periods showed a flat trend in abundance since 1994 for sandbar shark. For dusky shark, the abundance trend declined over the length of the series but an increase in abundance was observer in latter years. The time series for blacknose shark indicated an increase in abundance since 1994.

Introduction

Observations by at-sea observers of the shark-directed bottom longline fishery in the Atlantic Ocean and Gulf of Mexico have been conducted since 1994 (e.g. Hale and Carlson, 2007, Hale et al., 2007, Morgan et al. 2009, Hale et al., 2009). Currently 217 U.S. fishers are permitted to target sharks (excluding dogfish) in the Atlantic Ocean and Gulf of Mexico, and an additional 279 fishers are permitted to land sharks incidentally. Amendments to the Consolidated Atlantic Highly Migratory Species Fishery Management Plan based on stock assessments have eliminated the major directed shark fishery in the U.S. Atlantic (NMFS, 2007). The amendments implemented a shark research fishery, which allows NMFS to select a limited number of commercial shark vessels on an annual basis to collect life history data and catch data for future stock assessments. Beginning in 2008, only commercial shark fishers participating in the research fishery are allowed to land sandbar sharks, *Carcharhinus plumbeus*, and must carry an observer on 100% of all trips (compared to a coverage level of 4-6% outside the research fishery). Outside the research fishery, fishers are permitted to land 33 non-sandbar large coastal sharks (including blacktip shark, *Carcharhinus limbatus*, bull shark, *Carcharhinus leucas*, lemon shark, *Negaprion brevirostris*, nurse shark, *Ginglymostoma cirratum*, silky shark, *Carcharhinus falciformis*, spinner shark, *Carcharhinus brevipinna*, tiger shark, *Galeocerdo cuvier*, great hammerhead shark, *Sphyrna mokarran*, and scalloped hammerhead shark, *Sphyrna lewini*)

Methods

Catch rate analysis

A combined data set was developed based on observer programs from Morgan et al. (2009) and Hale et al. (2010). Because observations of the fishery have been conducted using two different non-overlapping sampling strategies (i.e. voluntary and mandatory vessel selection), catch rates were modeled independently for two time series representing periods of 1994-2001 (voluntary) and 2002-2009 (mandatory). In addition, with the introduction of the sandbar shark research fishery, some vessels were not subjected to random selection whereas others outside the research fishery were not permitted to land sandbar sharks. Because of this switch, a factor (research fishery) was added to account for the differences in target and harvest of sharks. Catch rates were standardized in a two-part generalized linear model analysis using the PROC GENMOD procedure in SAS (SAS Inst., Inc.). For the purposes of analysis, several categorical variables were constructed:

-"Year" = 1994-2001, 2002-2009

- "Area": location of set (Figure 1).
South Atlantic Ocean=South of 36°31' N to 24°32' N including the straights of Florida
Gulf of Mexico

- "Time of Day": the time of day the set started defined from the time the first hook was set in the water;
Day=0501-1800 hrs
Night=1801-0500 hrs

-"Season"
Winter=Jan-Mar
Spring=Apr-Jun
Summer=Jul-Sep
Fall=Oct-Dec

-"Depth": defined as the mean depth when the first hook was set and the last hook was retrieved.
0-100 ft
100-200 ft
200-300 ft
>300 ft

-"Hooktype": the hook that was used by the majority of the set
Large hook (>size 13 hook)
Medium (size 10-13 hook)
Small hook (<size 10 hook)
Undefined hook

-"Baitype": the bait that was used by the majority of the set
Clupeid/mullet
Teleost (general)
Elasmobranch
Tuna
Other (undefined or multiple bait types)

Research
-Yes (a set conducted under the sandbar research fishery)
-No (a set not conducted under the sandbar research fishery)

The proportion of sets that caught sharks (when at least one shark was caught) was modeled assuming a binomial distribution with a logit link function. Positive catches were modeled using a dependent variable of the natural logarithm of CPUE expressed as the natural logarithm of the number of sharks caught per 10^{-5} hook hours, i.e.:

CPUE=log [(sharks kept+sharks released)/(number of hooks*soak time/100000)]

Initially, a null model was run with no factors entered into the model. Models were then fit in a stepwise forward manner adding one independent variable. Each factor was ranked from greatest to least reduction in deviance per degree of freedom when compared to the null model. The factor with the greatest reduction in deviance was then incorporated into the model providing the effect was significant at $p<0.05$ based on a Chi-Square test, and the deviance per degree of freedom was reduced by at least 1% from the less complex model. The process was continued until no factors met the criterion for incorporation into the final model. Regardless of its level of significance, year was kept in all final models. After selecting the set of fixed factors and interactions for each error distribution, all interactions that included the factor year were treated as random interactions (Ortiz and Arocha, 2004). This process converted the basic models from generalized linear models into generalized linear mixed models. The final model determination was evaluated using the Akaike Information Criteria (AIC), and Schwarz's Bayesian Criterion (BIC). Models with smaller AIC and BIC values are preferred to those with larger values. These models were fit using a SAS macro, GLIMMIX (glmm800MaOB.sas: Russ Wolfinger, SAS Institute Inc.) and the MIXED procedure in SAS statistical

computer software (PROC GLIMMIX). Relative indices of abundance were calculated as the product of the year effect least square means from the two independent models.

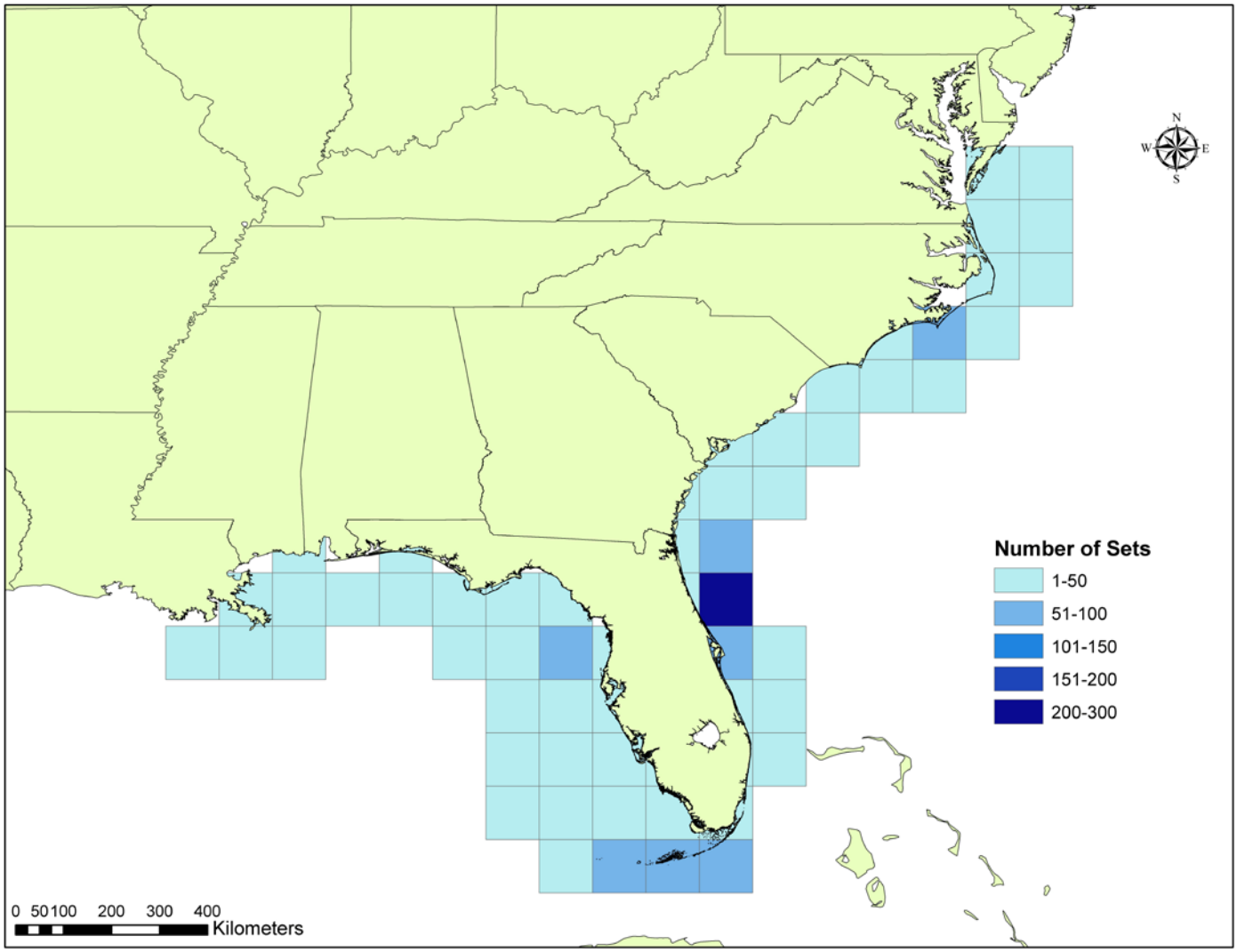
Size Information

Length information for sharks obtained from the Longline Observer Program was analyzed using regression analysis to examine trends in size with time (year).

Results and Discussion

A total of 820 longline sets from 1994-2001 and 904 sets from 2002-2009 contained essential data necessary to standardize catch rates. Locations of sets made can be found in Figure 1.

Figure 1. Distribution of fishing effort in the directed shark bottom longline fishery 1994-2009. Individual plots by year and in some locations were not possible because of vessel confidentiality.



Sandbar shark

The proportion of positive sets (i.e. at least one sandbar shark was caught) was 70.7% from 1994-2001 and 74.7% from 2002-2009. The stepwise construction of the models is summarized in Table 1. The index statistics can be found in Table 2. The delta-lognormal abundance index is shown in Figure 2. To allow for visual comparison with the nominal values, both series were scaled to their respective maximum value. The catch rate series indicated a sharp increase for 2009 but given the biology of sandbar shark the increase is likely a reflection of the sandbar shark research fishery rather than a change in abundance. Table 3 provides a table of the frequency of observations by factor and level. Diagnostic plots assessing the fit of the models were deemed acceptable (Figure 3).

Table 1. Analysis of deviance of explanatory variables for the binomial and lognormal generalized linear formulations of the proportion of positive and positive catches for sandbar shark for the voluntary (1994-2001) and mandatory portions (2002-2009) of observer coverage. Model is bold is the final selected model.

Voluntary (1994-2001)

Proportion positive-Binomial error distribution							
FACTOR	**DF**	**DEVIANCE**	**DEVIANCE/DF**	**%DIFF**	**DELTA%**	**CHISQUARE**	**PR>CHI**
NULL	819	991.4398	1.211				
YEAR	812	957.5668	1.179	2.584	2.584	33.87	<.0001
YEAR+							
BAIT	808	848.2973	1.050	13.273	10.689	109.27	<.0001
TIME	811	857.2576	1.057	12.681		100.31	<.0001
DEPTH	809	887.9654	1.098	9.330		69.6	<.0001
HOOKTYPE	809	900.0959	1.113	8.091		57.47	<.0001
AREA	811	950.9724	1.173	3.136		6.59	0.0102
SEASON	809	951.273	1.176	2.865		6.29	0.0981
YEAR+BAIT							
DEPTH	805	800.8352	0.995	17.820	4.547	47.46	<.0001
TIME	807	802.8623	0.995	17.816		45.43	<.0001
HOOKTYPE	805	824.636	1.024	15.378		23.66	<.0001
YEAR+BAIT+DEPTH	805	800.8352	0.995	17.820	17.820	47.46	<.0001
MIXED MODEL	**AIC**	**BIC**	**(-2) LOGLIKELIHOOD**				
YEAR+BAIT+DEPTH	**270.8**	**272.9**	**268.0**				
YEAR+BAIT+DEPTH YEAR*BAIT	270.8	272.4	268.8				
YEAR+BAIT+DEPTH YEAR*DEPTH	282.9	285.6	278.9				

Positive catches-Lognormal error distribution							
FACTOR	**DF**	**DEVIANCE**	**DEVIANCE/DF**	**%DIFF**	**DELTA%**	**CHISQUARE**	**PR>CHI**
NULL	579	1010.3377	1.745				
YEAR	572	947.5233	1.657	5.069	5.069	37.23	<.0001
YEAR+							
AREA	571	885.2044	1.550	11.158	6.088	39.46	<.0001
TIME	571	922.2621	1.615	7.439		15.67	<.0001
DEPTH	569	928.2346	1.631	6.512		11.93	0.0076

HOOKTYPE	569	928.74	1.632	6.461		11.61	0.0088
SEASON	569	928.83	1.632	6.452		11.56	0.0091
BAIT	568	930.4494	1.638	6.124		10.55	0.0322
YEAR+AREA							
TIME	568	860.9466	1.516	13.136	1.978	16.12	0.0011
DEPTH	568	860.9466	1.516	13.136		16.12	0.0011
SEASON	568	864.1624	1.521	12.812		13.95	0.003
BAIT	567	874.7397	1.543	11.589		6.9	0.1414
HOOKTYPE	568	877.4937	1.545	11.466		5.07	0.1664
YEAR+AREA+TIME	568	860.9466	1.516	13.136	13.136	16.12	0.0011
MIXED MODEL	**AIC**	**BIC**	**(-2) LOGLIKELIHOOD**				
YEAR+AREA+TIME	**1905.6**	**1909.9**	**1903.6**				
YEAR+AREA+TIME YEAR*AREA	1907.2	1908.6	1903.2				
YEAR+AREA+TIME YEAR*TIME	1905.6	1906.4	1903.6				

Mandatory (2002-2009)

Proportion positive-Binomial error distribution							
FACTOR	**DF**	**DEVIANCE**	**DEVIANCE/DF**	**%DIFF**	**DELTA%**	**CHISQUARE**	**PR>CHI**
NULL	903	1021.0728	1.131				
YEAR	896	946.1644	1.056	6.612	6.612	74.91	<.0001
YEAR+							
DEPTH	893	890.9885	0.998	11.763	5.150	55.18	<.0001
TIME	895	915.7161	1.023	9.517		30.45	<.0001
RESEARCH	895	923.939	1.032	8.704		22.23	<.0001
BAIT	892	925.1375	1.037	8.278		21.03	0.0003
HOOKTYPE	893	928.0944	1.039	8.088		18.07	0.0004
AREA	895	932.8054	1.042	7.828		13.36	0.0003
SEASON	893	940.824	1.054	6.827		5.34	0.1485
YEAR+DEPTH							
TIME	892	858.6141	0.963	14.874	3.111	32.37	<.0001
HOOKTYPE	890	876.174	0.984	12.937		27.97	<.0001
BAIT	889	881.706	0.992	12.289		22.43	0.0002
RESEARCH	892	885.6941	0.993	12.189		18.45	<.0001
AREA	892	893.231	1.001	11.442		10.91	0.0010
YEAR+DEPTH+TIME	892	858.6141	0.963	14.874	3.111	32.37	<.0001
MIXED MODEL	**AIC**	**BIC**	**(-2) LOGLIKELIHOOD**				
YEAR+DEPTH+TIME	156.8	154.8	158.5				
YEAR+DEPTH+TIME YEAR*DEPTH	156.9	159.7	152.9				
YEAR+DEPTH+TIME YEAR*TIME	**155.2**	**156.6**	**151.2**				

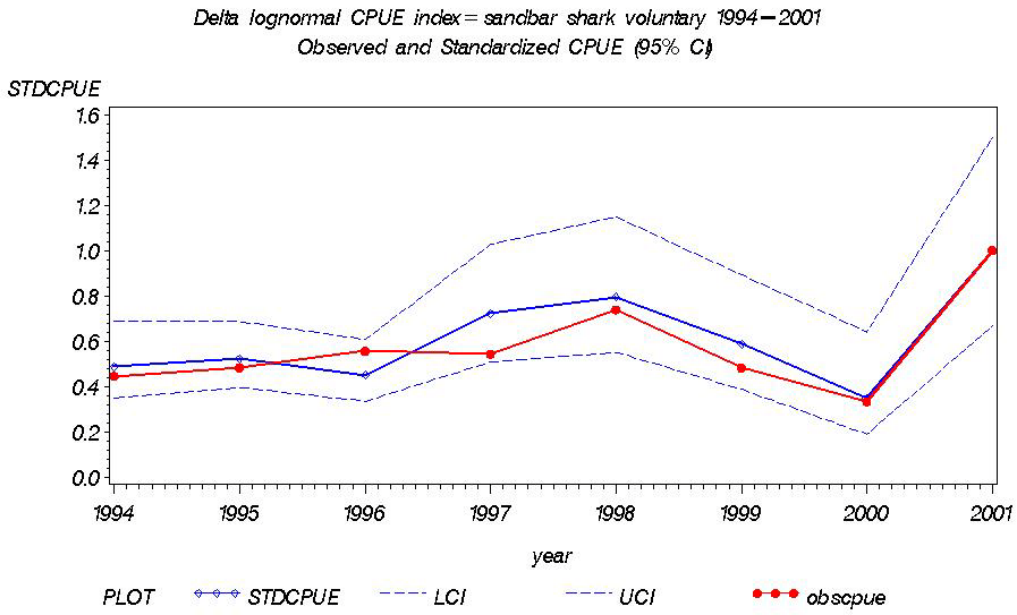
Positive catches-Lognormal error distribution							
FACTOR	**DF**	**DEVIANCE**	**DEVIANCE/DF**	**%DIFF**	**DELTA%**	**CHISQUARE**	**PR>CHI**
NULL	675	1165.5003	1.727				
YEAR	668	982.4696	1.471	14.821	14.821	115.49	<.0001
YEAR+							
AREA	667	958.5106	1.437	16.773	1.953	16.69	<.0001
DEPTH	665	967.0346	1.454	15.781		10.7	0.0134

RESEARCH	667	967.0193	1.450	16.035		10.72	0.0011
SEASON	665	965.3812	1.452	15.925		11.86	0.0079
TIME	667	978.844	1.468	15.008		2.5	0.1139
BAIT	664	974.9253	1.468	14.966		5.21	0.2663
HOOKTYPE	665	976.8198	1.469	14.928		3.9	0.2726
YEAR+AREA							
YEAR+AREA+DEPTH	664	939.0996	1.414	18.090	1.317	13.83	0.0031
SEASON	664	936.5191	1.410	18.315		15.69	0.0013
RESEARCH	666	941.2912	1.413	18.146		12.25	0.0005
TIME	664	945.3544	1.424	17.545		9.34	0.0251
YEAR+AREA+DEPTH	664	939.0996	1.414	18.090	1.317	13.83	0.0031
MIXED MODEL	**AIC**	**BIC**	**(-2) LOGLIKELIHOOD**				
YEAR+AREA+DEPTH	2169.7	2174.2	2167.7				
YEAR+AREA+DEPTH YEAR*AREA	**2153.5**	**2155.0**	**2149.5**				
YEAR+AREA+DEPTH YEAR*DEPTH	2169.7	2171.0	2167.7				

Table 2. The absolute standardized and nominal index of abundance for sandbar shark with the associated coefficients of variation (CV) and number of sets observed (N).

Year	Standardized index	CV	N	Nominal index	CV
1994	142.35	0.17	102	136.59	1.49
1995	151.62	0.14	162	148.22	1.77
1996	131.02	0.15	126	170.49	2.19
1997	210.17	0.18	80	166.78	1.50
1998	231.34	0.19	110	226.58	1.66
1999	170.87	0.21	99	147.82	1.48
2000	101.08	0.31	64	102.24	2.00
2001	290.99	0.20	77	306.70	1.23
2002	120.76	0.40	132	152.60	2.31
2003	172.03	0.37	171	174.81	1.52
2004	134.29	0.38	120	154.17	1.35
2005	175.96	0.42	127	265.29	2.31
2006	247.30	0.40	117	142.21	1.89
2007	327.74	0.41	62	295.93	1.28
2008	245.22	0.43	61	262.66	1.40
2009	836.28	0.37	114	847.56	1.14

Figure 2. Nominal (obscpue) and standardized (STDCPUE) indices of abundance for sandbar shark. The dashed lines are the 95% confidence limits (LCL, UCL) for the standardized index. Each index has been divided by the maximum of the index.



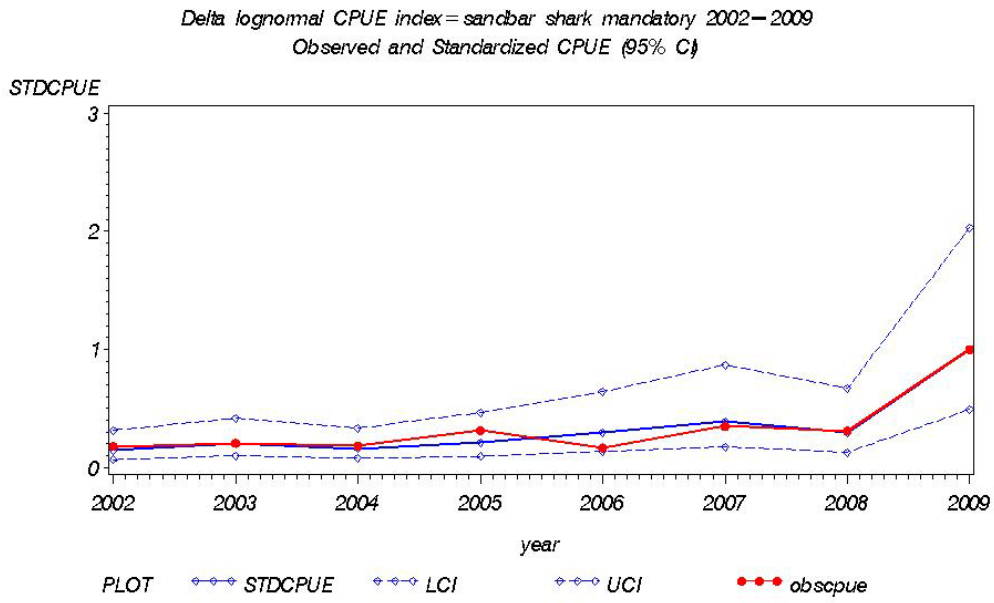
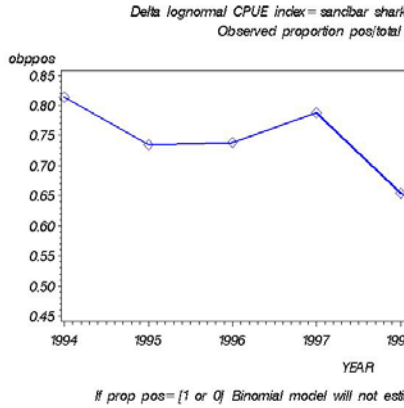


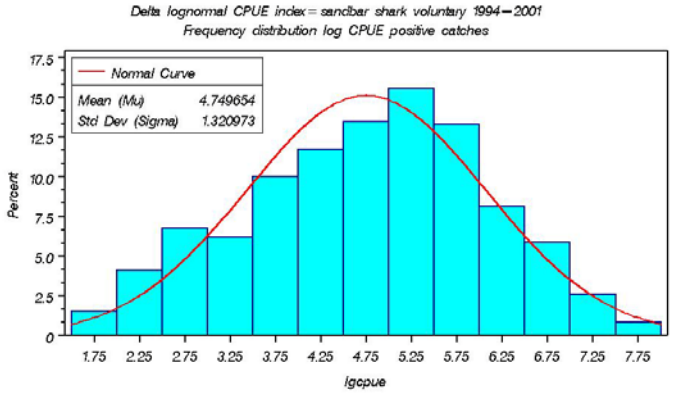
Table 3. Frequency of observations by factor and level used in the development of the standardized catch rate series.

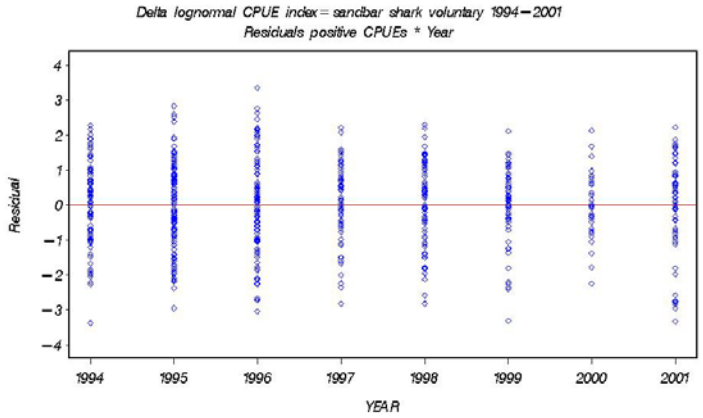
FACTOR	SERIES	LEVEL	FREQUENCY OF

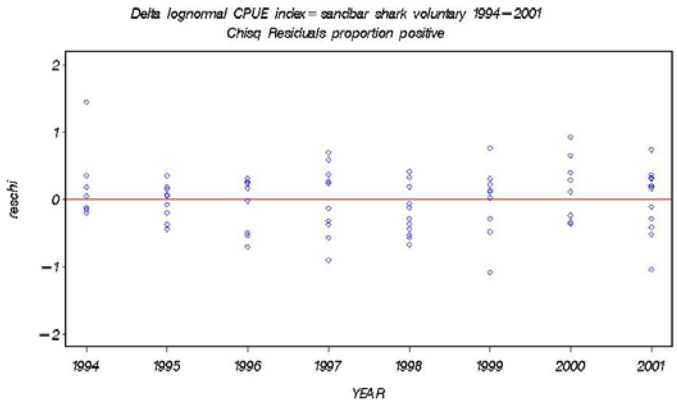
			TOTAL
YEAR	Voluntary	1994	12.4
		1995	19.8
DEPTH	Voluntary	0-100	57.4
		1996	15.4
		100-200	30.1
		1997	9.8
		200-300	8.9
		1998	13.4
		≥300	3.5
		1999	12.1
		2000	7.8
	Mandatory	0-100	42.6
		2001	9.4
		100-200	32.0
		200-300	15.3
	Mandatory	2002	14.6
		≥300	10.2
		2003	18.9
		2004	13.3
BAITTYPE	Voluntary	Clupeid	4.6
		2005	14.0
		Elasmobranch	17.7
		2006	12.9
		Other	70.1
		2007	6.9
		Teleost	4.3
		2008	6.7
		Tuna	3.3
		2009	12.6
	Mandatory	Clupeid	2.1
AREA	Voluntary	Gulf	31.5
		Elasmobranch	19.6
		South Atlantic	68.5
		Other	43.6
		Teleost	9.7
	Mandatory	Gulf	54.6
		Tuna	25.0
		South Atlantic	45.4
RESEARCH	Mandatory	Yes	17.9
SEASON	Voluntary	Fall	0.6
FISHERY		Spring	7.3
		No	82.1
		Summer	39.9
		Winter	52.2
	Mandatory	Fall	8.4
		Spring	10.3
		Summer	49.4
		Winter	31.9
TIMEOFDAY	Voluntary	Day	28.2
		Night	71.8
	Mandatory	Day	22.5
		Night	77.5
HOOKTYPE	Voluntary	Large	56.3
		Medium	3.7
		Other	37.2
		Small	2.8
	Mandatory	Large	71.7
		Medium	11.7
		Other	12.7
		Small	3.9

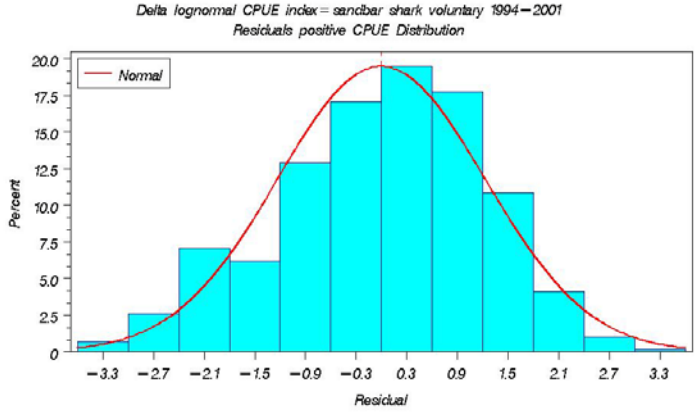
Figure 3. Diagnostic plots of the frequency distribution of residuals, quantile-quantile plots, and distribution of residuals by year from the lognormal model for sandbar shark.

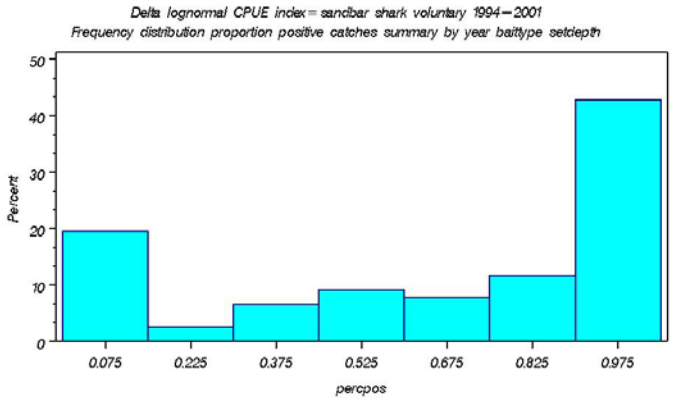


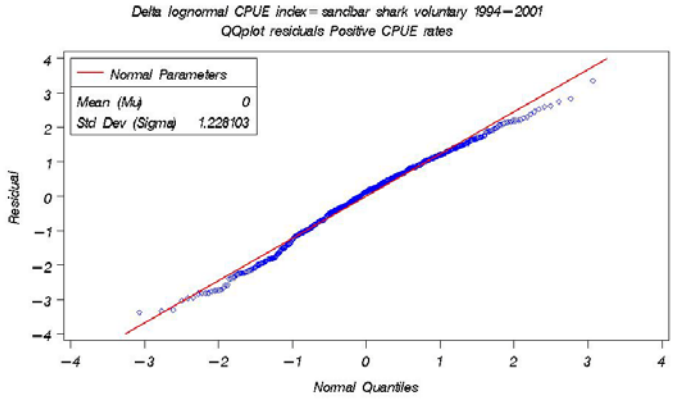

Delta lognormal CPUE index=sandbar shark voluntary 1994–2001
Frequency distribution log CPUE positive catches
Normal Curve
Mean (Mu) 4.749654
Std Dev (Sigma) 1.320973
Percent
lgcpue

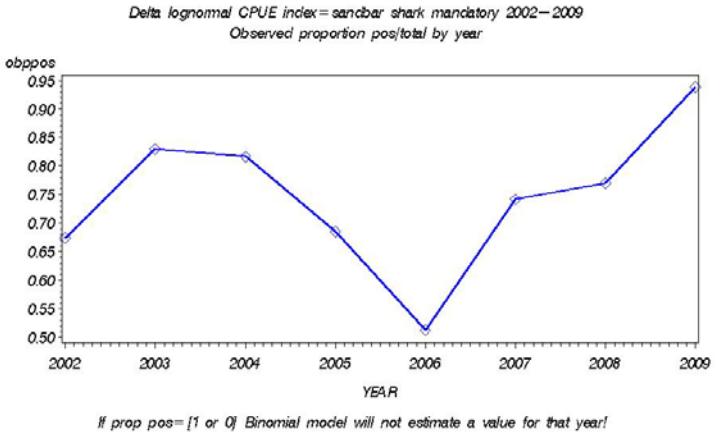

Delta lognormal CPUE index=sandbar shark voluntary 1994–2001
Residuals positive CPUEs * Year
Residual
YEAR

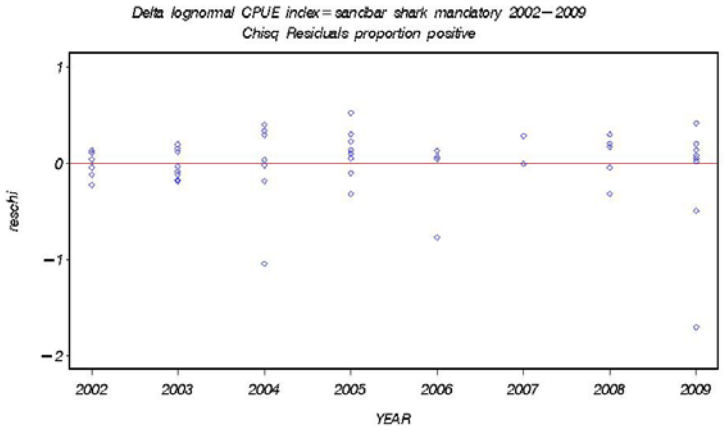

Delta lognormal CPUE index=sandbar shark voluntary 1994–2001
Chisq Residuals proportion positive
reschi
YEAR

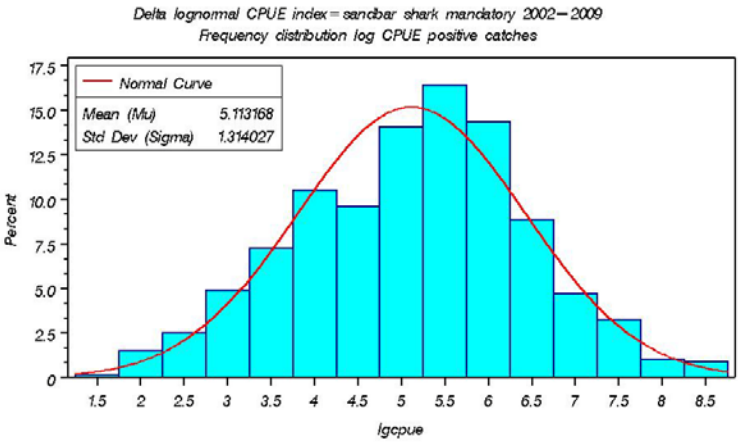

Delta lognormal CPUE index=sandbar shark voluntary 1994–2001
Residuals positive CPUE Distribution
Normal
Percent
Residual

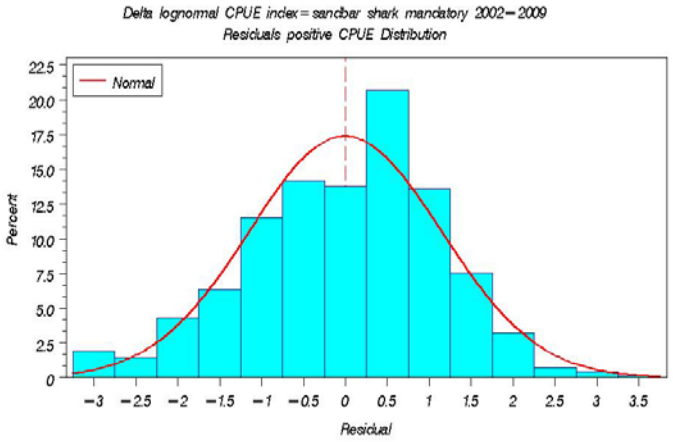

Delta lognormal CPUE index=sandbar shark voluntary 1994–2001
Frequency distribution proportion positive catches summary by year baitype setdepth
Percent
percpos

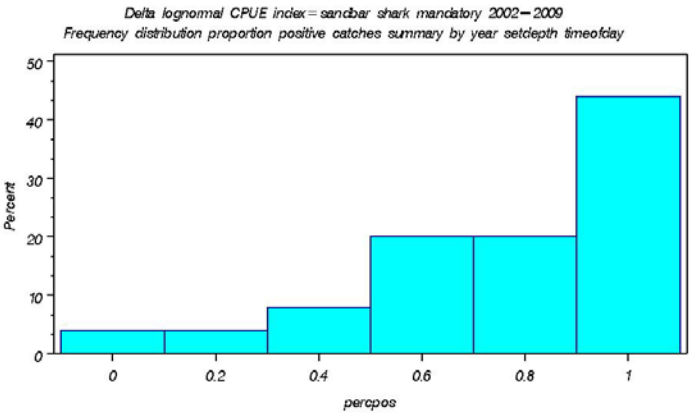

Delta lognormal CPUE index=sandbar shark voluntary 1994–2001
QQplot residuals Positive CPUE rates
Normal Parameters
Mean (Mu) 0
Std Dev (Sigma) 1.228103
Residual
Normal Quantiles

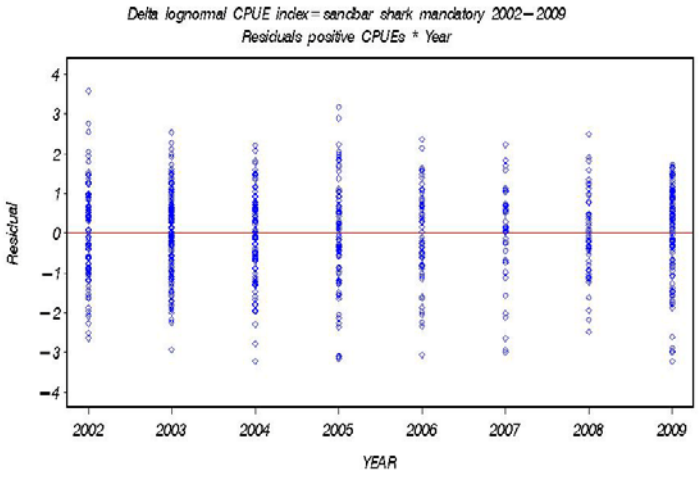

Delta lognormal CPUE index=sandbar shark mandatory 2002–2009
Observed proportion pos/total by year
obppos
YEAR
If prop pos=[1 or 0] Binomial model will not estimate a value for that year!

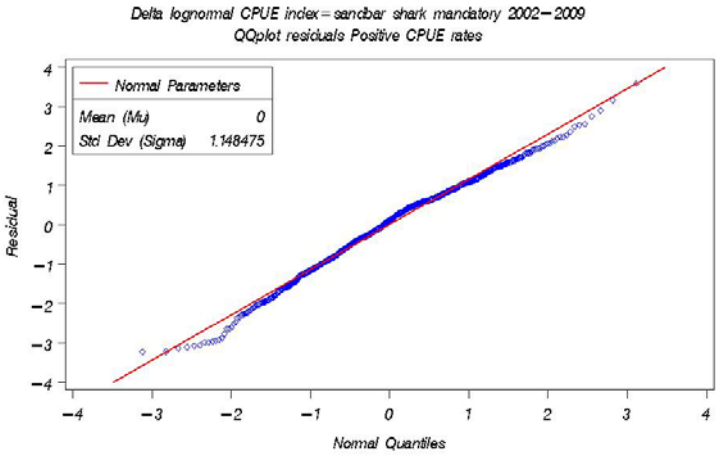

Delta lognormal CPUE index=sandbar shark mandatory 2002–2009
Chisq Residuals proportion positive
reschi
YEAR


Delta lognormal CPUE index=sandbar shark mandatory 2002–2009
Frequency distribution log CPUE positive catches
Normal Curve
Mean (Mu) 5.113168
Std Dev (Sigma) 1.314027
Percent
lgcpue


Delta lognormal CPUE index=sandbar shark mandatory 2002–2009
Residuals positive CPUE Distribution
Normal
Percent
Residual


Delta lognormal CPUE index=sandbar shark mandatory 2002–2009
Frequency distribution proportion positive catches summary by year setdepth timeofday
Percent
percpos


Delta lognormal CPUE index=sandbar shark mandatory 2002–2009
Residuals positive CPUEs * Year
Residual
YEAR



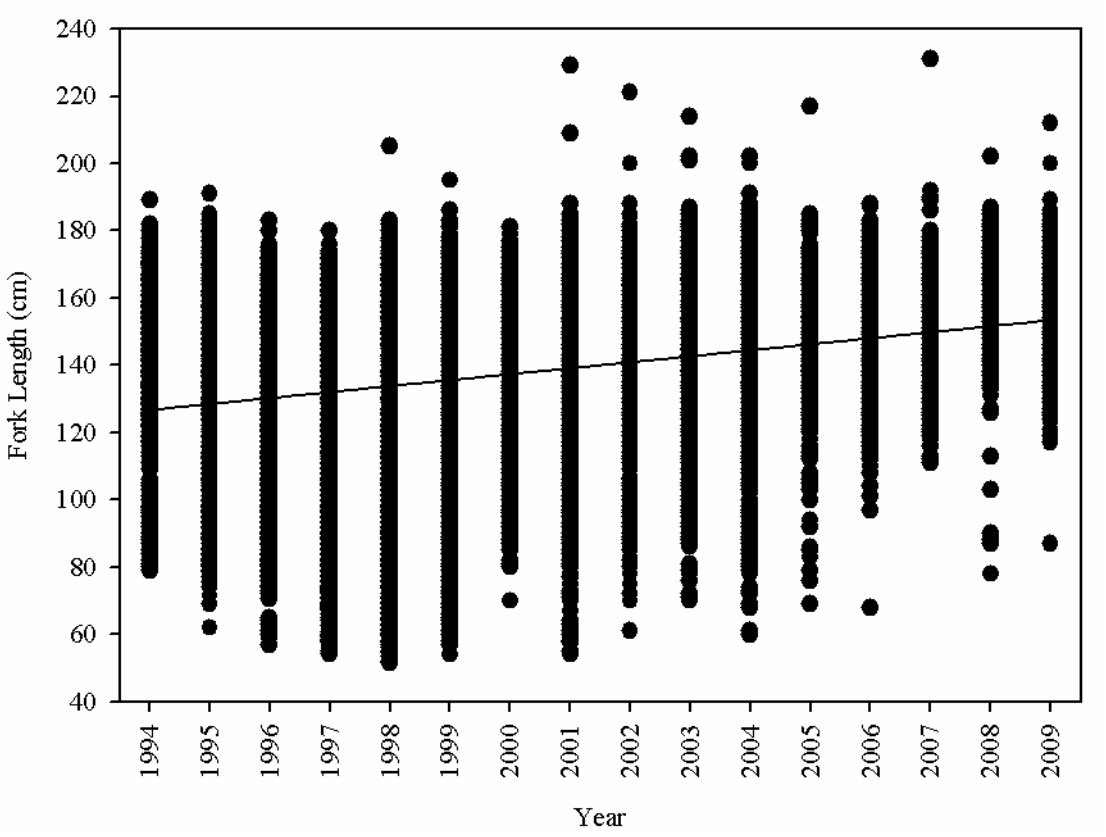
Trends in size

Linear regressions fit to fork lengths of sharks caught from the observer program indicated a significant increase ($p<0.0001$, $r^2=0.11$) in length over time. Data from 1994 to 2009 showed a slight increasing trend (Figure 4) with mean size of 140.4 cm FL in 1994 and 156.2 cm FL in 2009 (Table 4).

Table 4. Average sandbar shark lengths by year from observations from 1994 through 2009.

Year	Average Size (cm FL)	Standard deviation (cm)	Sample size (n)
1994	140.43	18.43	1718
1995	136.74	24.54	2353
1996	130.17	25.28	1811
1997	128.47	28.44	1382
1998	117.27	26.66	2933
1999	128.43	34.25	1323
2000	134.52	23.96	687
2001	138.55	23.72	2779
2002	146.91	19.38	1424
2003	144.89	18.01	2812
2004	141.95	19.45	2107
2005	149.95	14.65	1254
2006	146.22	14.23	1066
2007	150.37	12.88	895
2008	155.70	12.83	597
2009	156.17	11.60	2728

Figure 4. Sandbar shark lengths by year from observations from 1994 through 2009.


Fork Length (cm)
240
220
200
180
160
140
120
100
80
60
40
1994
1995
1996
1997
1998
1999
2000
2001
2002
2003
2004
2005
2006
2007
2008
2009
Year

Dusky shark

The proportion of positive sets (i.e. at least one dusky shark was caught) was 28.7% from 1994-2001 and 14.0% from 2002-2009. The stepwise construction of the models is summarized in Table 5. The index statistics can be found in Table 6. The delta-lognormal abundance index is shown in Figure 5. To allow for visual comparison with the nominal values, both series were scaled to their respective maximum value. Table 3 provides a table of the frequency of observations by factor and level. Diagnostic plots assessing the fit of the models were deemed acceptable (Figure 6).

Table 5. Analysis of deviance of explanatory variables for the binomial and lognormal generalized linear formulations of the proportion of positive and positive catches for dusky shark for the voluntary (1994-2001) and mandatory portions (2002-2009) of observer coverage. Model is bold is the final selected model.

Voluntary (1994-2001)

Proportion positive-Binomial error distribution							
FACTOR	**DF**	**DEVIANCE**	**DEVIANCE/DF**	**%DIFF**	**DELTA%**	**CHISQUARE**	**PR>CHI**
NULL	819	984.2862	1.202				
YEAR	812	960.5438	1.183	1.571	1.571	23.74	0.0013
YEAR+							
AREA	811	848.0973	1.046	12.986	11.415	112.45	<.0001
BAIT	808	913.6263	1.131	5.915		46.92	<.0001
DEPTH	809	925.4037	1.144	4.820		35.14	<.0001
HOOKTYPE	809	935.7542	1.157	3.756		24.79	<.0001
SEASON	809	947.636	1.171	2.533		12.91	0.0048
TIME	811	960.533	1.184	1.451		0.01	0.9169
YEAR+AREA							
BAIT	807	807.1031	1.000	16.782	3.796	40.99	<.0001
DEPTH	808	837.1023	1.036	13.796		10.99	0.0118
YEAR+BAIT+DEPTH	807	807.1031	1.000	16.782	3.796	40.99	<.0001
MIXED MODEL	**AIC**	**BIC**	**(-2) LOGLIKELIHOOD**				
YEAR+BAIT+DEPTH	**155.4**	**157.0**	**153.4**				
YEAR+BAIT+DEPTH YEAR*BAIT	274.9	278.0	270.9				
YEAR+BAIT+DEPTH YEAR*DEPTH	265.4	268.2	261.4				
Positive catches-Lognormal error distribution							
FACTOR	**DF**	**DEVIANCE**	**DEVIANCE/DF**	**%DIFF**	**DELTA%**	**CHISQUARE**	**PR>CHI**
NULL	235	278.8693	1.187				
YEAR	228	259.7899	1.139	3.982	3.982	16.73	0.0193
YEAR+							
SEASON	225	237.5826	1.056	11.019	7.037	21.09	0.0001
AREA	227	242.4567	1.068	9.993		16.3	<.0001
TIME	227	244.8793	1.079	9.094		13.95	0.0002
BAIT	224	252.5505	1.127	4.990		6.67	0.1544
DEPTH	225	255.3477	1.135	4.365		4.07	0.254
HOOKTYPE	226	256.9189	1.137	4.202		2.62	0.2695

YEAR+SEASON							
AREA	224	220.9376	0.986	16.883	5.865	17.14	<.0001
TIME	224	228.8918	1.022	13.891		8.79	0.003
BAIT	221	231.0929	1.046	11.883		6.54	0.1625
YEAR+SEASON+AREA							
TIME	223	214.618	0.962	18.899	2.015	6.85	0.0089
MIXED MODEL	**AIC**	**BIC**	**(-2) LOGLIKELIHOOD**				
YEAR+SEASON+AREA+TIME	666.6	670	664.6				
YEAR+SEASON+AREA+TIME YEAR*SEASON	**664.3**	**666.2**	**660.3**				
YEAR+SEASON+AREA+TIME YEAR*AREA	668.6	670	664.2				
YEAR+SEASON+AREA+TIME YEAR*TIME	668.2	668	664				

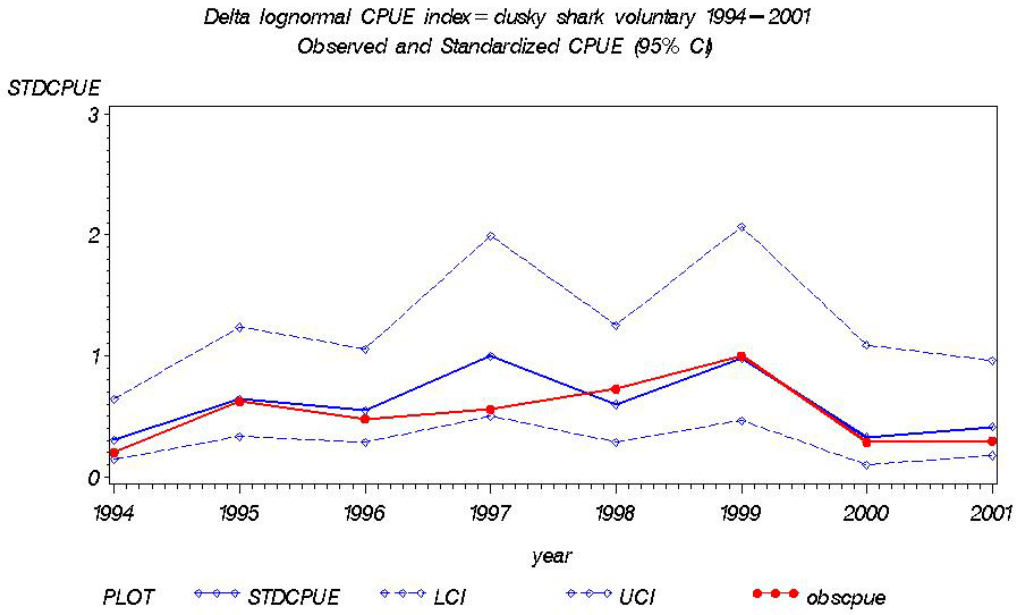
Mandatory (2002-2009)

Proportion positive-Binomial error distribution							
FACTOR	**DF**	**DEVIANCE**	**DEVIANCE/DF**	**%DIFF**	**DELTA%**	**CHISQUARE**	**PR>CHI**
NULL	903	733.7697	0.813				
YEAR	896	712.8292	0.796	2.095	2.095	20.94	0.0039
YEAR+							
DEPTH	893	700.515	0.784	3.463	1.368	12.31	0.0064
AREA	895	702.3681	0.785	3.424		10.46	0.0012
SCIENTIFIC	895	706.2592	0.789	2.889		6.57	0.0104
BAIT	892	708.672	0.794	2.229		4.16	0.3851
HOOKTYPE	893	709.8224	0.795	2.180		3.01	0.3906
TIME	895	711.742	0.795	2.135		1.09	0.2971
SEASON	893	711.4602	0.797	1.955		1.37	0.7128
YEAR+DEPTH	893	700.515	0.784	3.463	1.368	12.31	0.0064
MIXED MODEL	AIC	BIC	(-2) LOGLIKELIHOOD				
YEAR+DEPTH	**68.2**	**69.1**	**66.2**				
YEAR+DEPTH YEAR*DEPTH	68.2	69.5	66.2				
Positive catches-Lognormal error distribution							
FACTOR	**DF**	**DEVIANCE**	**DEVIANCE/DF**	**%DIFF**	**DELTA%**	**CHISQUARE**	**PR>CHI**
NULL	126.0	144.3	1.145				
YEAR	119	132.2352	1.111	2.937	2.937	11.05	0.1367
YEAR+							
AREA	118	124.0665	1.051	8.161	5.224	8.1	0.0044
BAIT	115	123.9819	1.078	5.830		8.18	0.085
SCIENTIFIC	119	132.2352	1.111	2.937		0	
DEPTH	116	129.1495	1.113	2.750		3	0.3918
TIME	118	131.9496	1.118	2.326		0.27	0.6002
HOOKTYPE	116	130.7787	1.127	1.524		1.41	0.704
SEASON	116	130.8706	1.128	1.454		1.32	0.725
MIXED MODEL	AIC	BIC	(-2) LOGLIKELIHOOD				
YEAR+AREA	**367.1**	**369.8**	**365.1**				
YEAR+AREA YEAR*AREA	367.9	369.3	363.9				

Table 6. The absolute standardized and nominal index of abundance for dusky shark with the associated coefficients of variation (CV) and number of sets observed (N).

Year	Standardized index	CV	N	Nominal index	CV
1994	6.64	0.39	102	5.93	1.94
1995	14.05	0.34	162	18.39	2.79
1996	12.01	0.34	126	14.20	2.82
1997	21.86	0.36	80	16.59	2.03
1998	13.11	0.38	110	21.47	3.64
1999	21.46	0.39	99	29.58	4.05
2000	7.16	0.66	64	8.43	4.25
2001	9.02	0.44	77	8.80	3.01
2002	2.73	0.51	132	3.55	6.93
2003	3.62	0.37	171	4.79	4.14
2004	3.98	0.38	120	3.91	2.84
2005	4.42	0.50	127	5.99	4.25
2006	5.54	0.55	117	3.85	5.38
2007	6.62	0.66	62	3.90	3.70
2008	9.29	0.62	61	6.02	3.58
2009	14.26	0.32	114	14.23	3.62

Figure 6. Nominal (obscpue) and standardized (STDCPUE) indices of abundance for dusky shark. The dashed lines are the 95% confidence limits (LCL, UCL) for the standardized index. Each index has been divided by the maximum of the index.



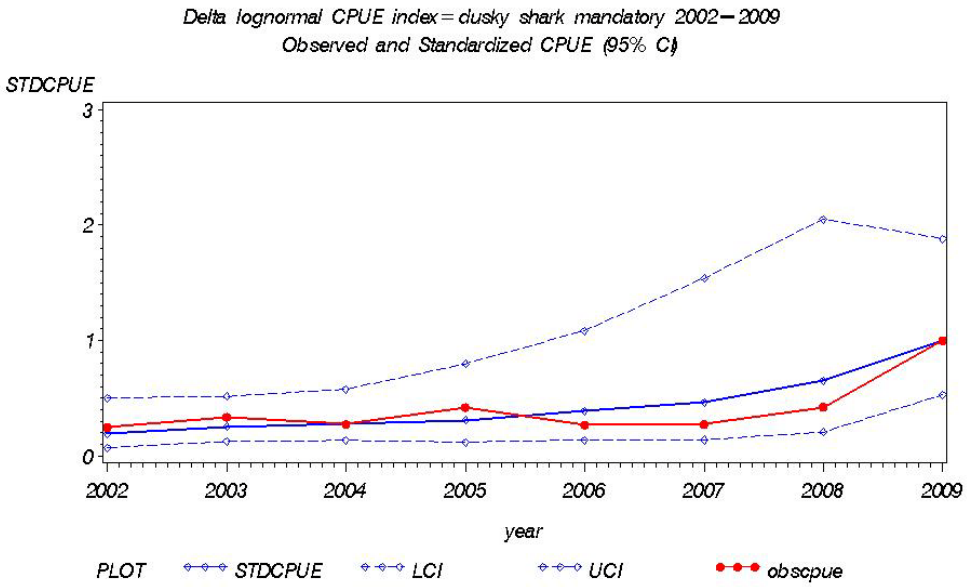
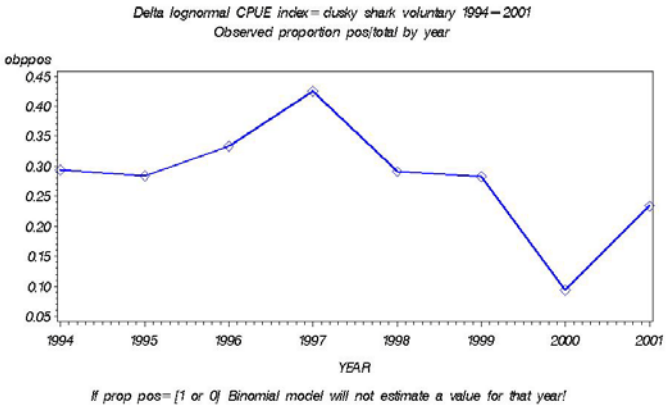
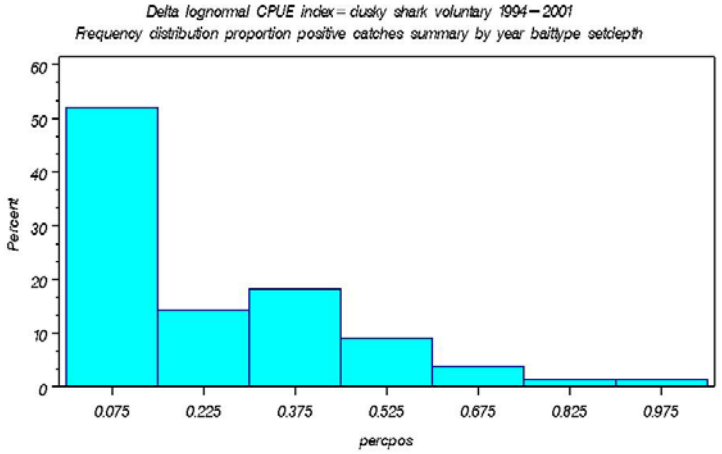
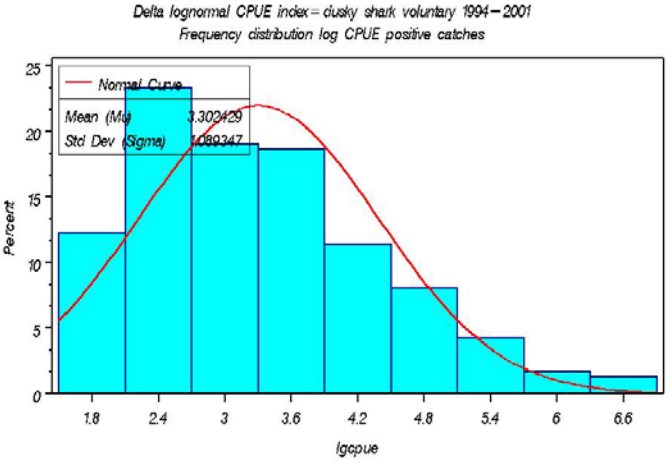


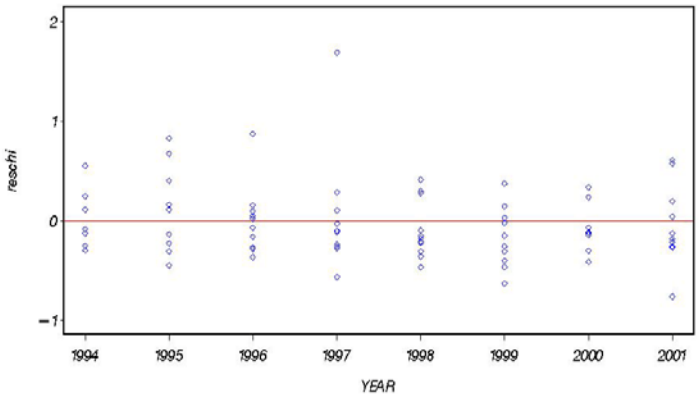
Figure 7. Diagnostic plots of the frequency distribution of residuals, quantile-quantile plots, and distribution of residuals by year for dusky shark.



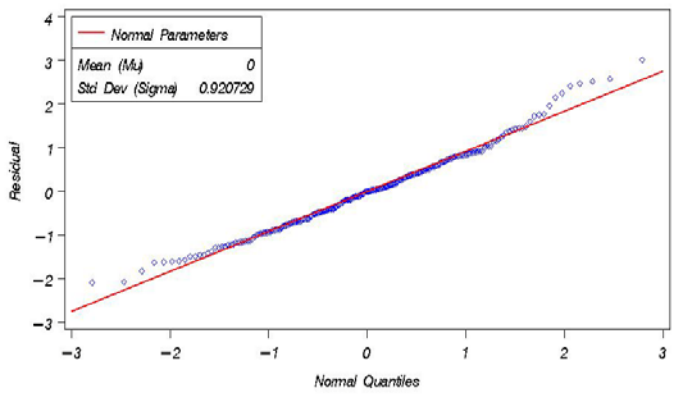




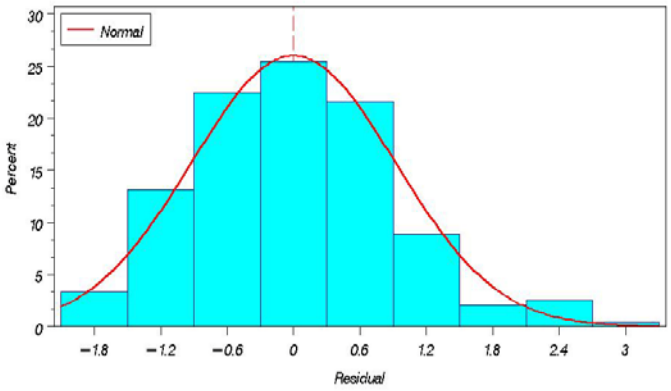
Delta lognormal CPUE index=dusky shark voluntary 1994–2001
Chisq Residuals proportion positive



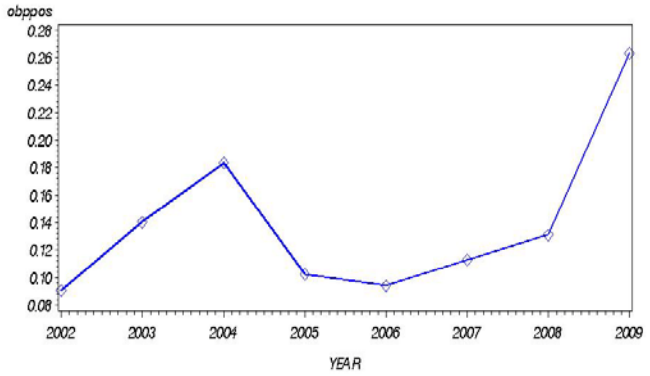
Delta lognormal CPUE index=dusky shark voluntary 1994–2001
QQplot residuals Positive CPUE rates



Delta lognormal CPUE index=dusky shark voluntary 1994–2001
Residuals positive CPUE Distribution

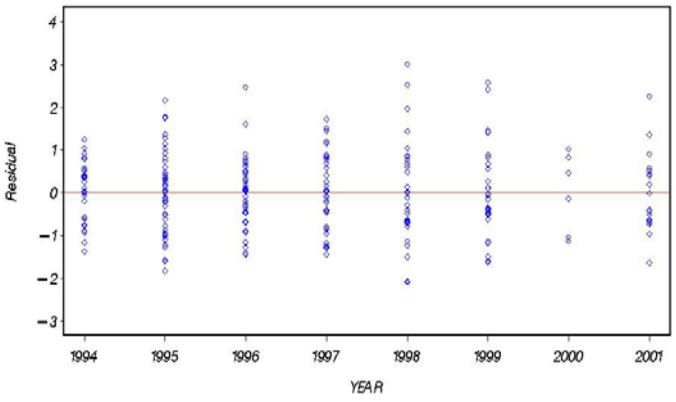


Delta lognormal CPUE index=dusky shark mandatory years 2002–2009
Observed proportion pos/total by year

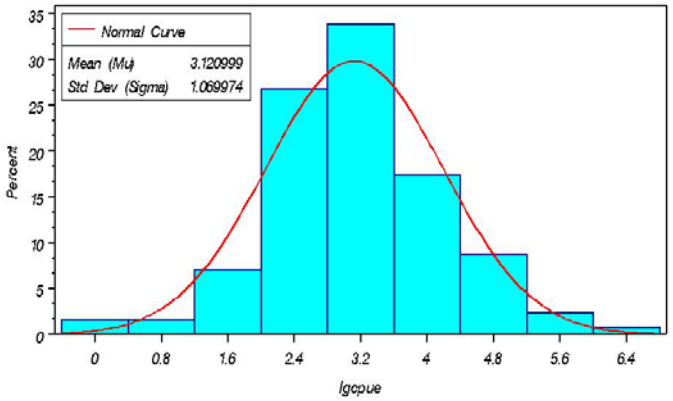


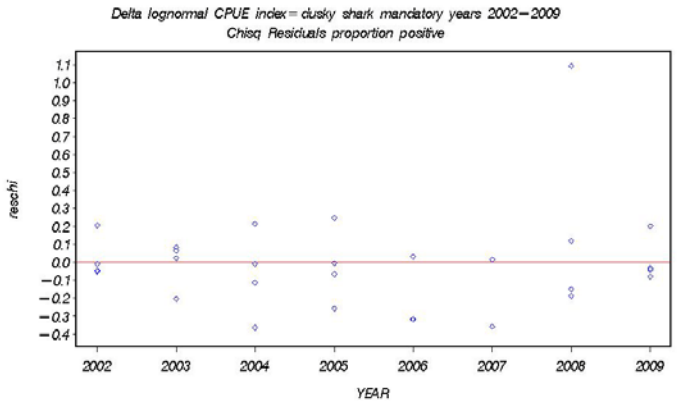
If prop pos=[1 or 0] Binomial model will not estimate a value for that year!

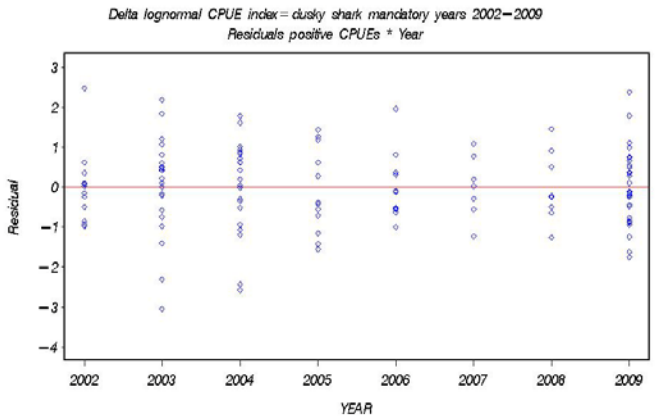
Delta lognormal CPUE index=dusky shark voluntary 1994–2001
Residuals positive CPUEs * Year

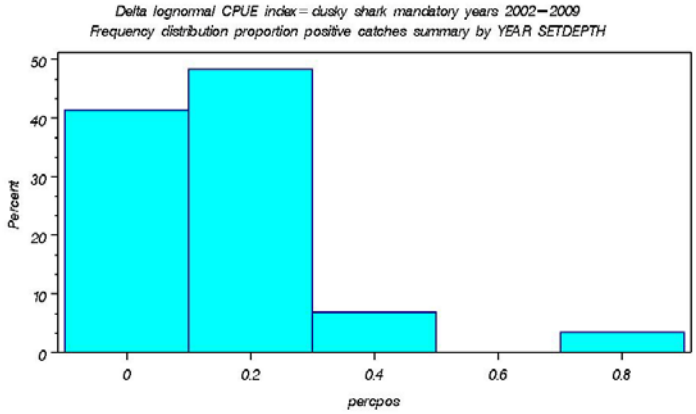


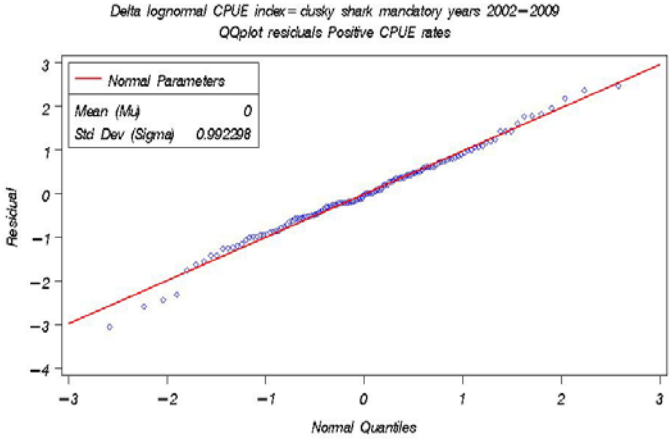
Delta lognormal CPUE index=dusky shark mandatory years 2002–2009
Frequency distribution log CPUE positive catches

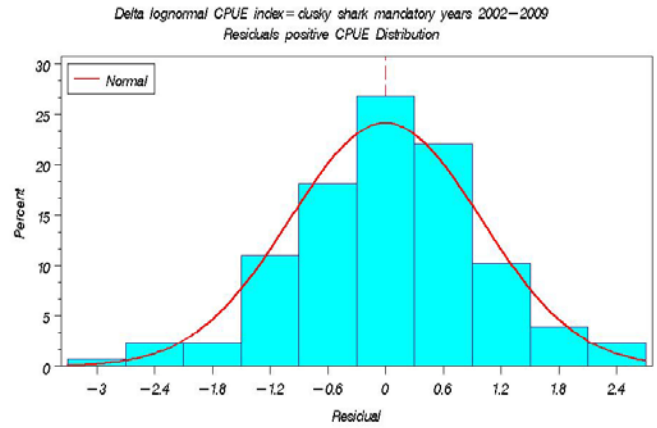












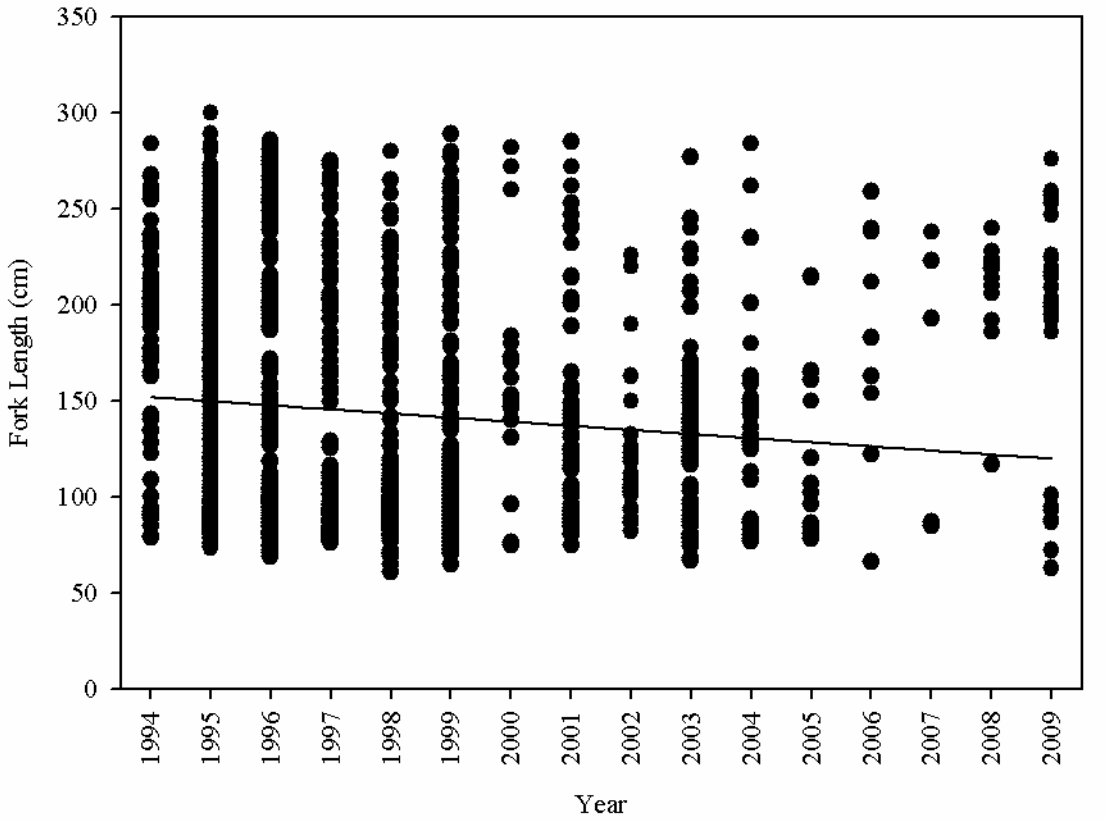
Trends in size

Linear regressions fit to fork lengths of sharks caught from the observer program indicated a significant decrease ($p<0.0001$, $r^2=0.01$) in length over time. While average size was not considerably different between 1994 and 2009, data from 1994 to 2009 showed a slight decreasing trend (Figure 8) (Table 7).

Table 7. Average dusky shark lengths by year from observations from 1994 through 2009.

Year	Average Size (cm FL)	Standard deviation (cm)	Sample size (n)
1994	185.37	56.41	72
1995	171.15	62.30	423
1996	155.77	69.31	196
1997	139.39	64.56	141
1998	107.41	39.09	316
1999	121.25	53.09	297
2000	162.74	57.24	19
2001	136.63	53.42	75
2002	118.90	37.19	29
2003	139.34	41.20	96
2004	142.15	49.29	33
2005	127.27	47.73	15
2006	181.89	62.78	9
2007	165.20	74.10	5
2008	205.27	33.14	11
2009	186.29	63.72	35

Figure 8. Dusky shark lengths by year from observations from 1994 through 2009.



Blacknose shark

The proportion of positive sets (i.e. at least one blacknose shark was caught) was 28.7% from 1994-2001 and 37.9% from 2002-2009. The stepwise construction of the models is summarized in Table 8. The index statistics can be found in Table 9. The delta-lognormal abundance index is shown in Figure 9. To allow for visual comparison with the nominal values, both series were scaled to their respective maximum value. Table 3 provides a table of the frequency of observations by factor and level. Diagnostic plots assessing the fit of the models were deemed acceptable (Figure 10).

Table 8. Analysis of deviance of explanatory variables for the binomial and lognormal generalized linear formulations of the proportion of positive and positive catches for blacknose shark for the voluntary (1994-2001) and mandatory portions (2002-2009) of observer coverage. Model is bold is the final selected model.

Voluntary (1994-2001)

Proportion positive-Binomial error distribution							
FACTOR	DF	DEVIANCE	DEVIANCE/DF	%DIFF	DELTA%	CHISQUARE	PR>CHI
NULL	819	984.2862	1.202				
YEAR	812	944.5799	1.163	3.207	3.207	39.71	<.0001
YEAR+							
BAIT	808	885.0196	1.095	8.861	5.654	59.56	<.0001
DEPTH	809	888.8223	1.099	8.583		55.76	<.0001
AREA	811	896.2741	1.105	8.043		48.31	<.0001
HOOKTYPE	809	931.7212	1.152	4.170		12.86	0.005
TIME	811	938.220	1.157	3.740		6.36	0.0117
SEASON	809	940.9771	1.163	3.218		3.6	0.3077
YEAR+BAIT							
DEPTH	805	842.1434	1.046	12.953	4.092	42.88	<.0001
AREA	807	845.7646	1.048	12.796		39.25	<.0001
HOOKTYPE	805	877.181	1.090	9.332		7.84	0.0495
TIME	807	884.323	1.096	8.820		0.70	0.4039
YEAR+BAIT+DEPTH							
AREA	804	777.814	0.967	19.503	6.549	64.33	<.0001
MIXED MODEL	**AIC**	**BIC**	**(-2) LOGLIKELIHOOD**				
YEAR+BAIT+DEPTH+AREA	412.6	415.1	410.6				
YEAR+BAIT+DEPTH+AREA YEAR*BAIT	412.6	414.2	410.6				
YEAR+BAIT+DEPTH+AREA YEAR*DEPTH	**412.6**	**414.0**	**410.6**				
YEAR+BAIT+DEPTH+AREA YEAR*AREA	420.0	421.4	416.0				
Positive catches-Lognormal error distribution							
FACTOR	**DF**	**DEVIANCE**	**DEVIANCE/DF**	**%DIFF**	**DELTA%**	**CHISQUARE**	**PR>CHI**
NULL	235	547.3333	2.329				
YEAR	228	477.3869	2.094	10.102	10.102	32.27	<.0001
YEAR+							
TIME	227	328.7211	1.448	37.825	27.723	88.06	<.0001
HOOKTYPE	225	355.5659	1.580	32.149		69.53	<.0001
AREA	227	389.98	1.718	26.238		47.73	<.0001

BAIT	224	409.3454	1.827	21.538		36.29	<.0001
DEPTH	225	463.7844	2.061	11.499		6.82	0.0778
SEASON	226	473.8368	2.097	9.981		1.76	0.4144
YEAR+TIME							
HOOKTYPE	224	290.5948	1.297	44.300	6.475	50.78	<.0001
AREA	226	314.485	1.392	40.254		10.45	0.0012
BAIT	223	319.8865	1.434	38.410		6.43	0.1693
YEAR+TIME+HOOKTYPE+							
AREA	223	290.1359	1.301	44.138	44.138	0.37	0.5414
MIXED MODEL	**AIC**	**BIC**	**(-2) LOGLIKELIHOOD**				
YEAR+TIME+HOOKTYPE	**733.6**	**737.0**	**731.6**				
YEAR+TIME+HOOKTYPE YEAR*TIME	734.0	735.5	730.0				
YEAR+TIME+HOOKTYPE YEAR*HOOKTYPE	733.7	735.8	729.7				

Mandatory (2002-2009)

Proportion positive-Binomial error distribution							
FACTOR	DF	DEVIANCE	DEVIANCE/DF	%DIFF	DELTA%	CHISQUARE	PR>CHI
NULL	903	1200.118	1.329				
YEAR	896	1162.608	1.298	2.369	2.369	37.51	<.0001
YEAR+							
AREA	895	924.067	1.032	22.314	19.945	238.54	<.0001
BAIT	892	1076.147	1.206	9.224		86.46	<.0001
DEPTH	893	1101.281	1.233	7.208		61.33	<.0001
SEASON	893	1149.956	1.288	3.107		12.65	0.0055
HOOKTYPE	893	1154.006	1.292	2.765		8.6	0.0351
SCIENTIFIC	895	1160.435	1.297	2.442		2.17	0.1404
TIME	895	1161.732	1.298	2.333		0.88	0.3491
YEAR+AREA							
DEPTH	892	840.925	0.943	29.066	6.752	83.14	<.0001
BAIT	891	899.241	1.009	24.061		24.83	<.0001
HOOKTYPE	892	916.230	1.027	22.714		7.84	0.0495
SEASON	892	923.143	1.035	22.130		0.92	0.8197
YEAR+AREA+DEPTH							
BAIT	888	812.332	0.915	31.169	2.103	28.59	<.0001
MIXED MODEL	**AIC**	**BIC**	**(-2) LOGLIKELIHOOD**				
YEAR+AREA+DEPTH+BAIT	592.7	595.6	590.7				
YEAR+AREA+DEPTH+BAIT YEAR*AREA	594.3	595.8	590.3				
YEAR+AREA+DEPTH+BAIT YEAR*DEPTH	591.7	594.5	587.7				
YEAR+AREA+DEPTH+BAIT YEAR*BAIT	**601.4**	**601.6**	**597.4**				
Positive catches-Lognormal error distribution							
FACTOR	**DF**	**DEVIANCE**	**DEVIANCE/DF**	**%DIFF**	**DELTA%**	**CHISQUARE**	**PR>CHI**
NULL	342	735.392	2.150				
YEAR	335	664.622	1.984	7.735	7.735	34.71	<.0001
YEAR+							

DEPTH	332	604.300	1.820	15.351	7.616	32.64	<.0001
TIME	334	639.704	1.915	10.928		13.11	0.0003
BAIT	331	640.569	1.935	9.999		12.64	0.0132
HOOKTYPE	332	647.765	1.951	9.262		8.81	0.0319
AREA	334	656.912	1.967	8.532		4	0.0454
SEASON	332	653.646	1.969	8.439		5.71	0.1265
SCIENTIFIC	334	664.301	1.989	7.503		0.17	0.6839
YEAR+DEPTH							
TIME	331	584.244	1.765	17.913	2.562	11.58	0.0007
HOOKTYPE	329	583.364	1.773	17.539		12.09	0.0071
BAIT	328	583.298	1.778	17.297		12.13	0.0164
YEAR+DEPTH+TIME							
BAIT	327	564.957	1.728	19.652	1.739	11.51	0.0214
HOOKTYPE	328	569.090	1.735	19.311		9.01	0.0291
MIXED MODEL	**AIC**	**BIC**	**(-2) LOGLIKELIHOOD**				
YEAR+DEPTH+TIME+BAIT	1164.1	1167.8	1162.1				
YEAR+DEPTH+TIME+BAIT YEAR*DEPTH	1164.1	1165.4	1162.1				
YEAR+DEPTH+TIME+BAIT YEAR*TIME	1164.1	1164.7	11621.1				
YEAR+DEPTH+TIME+BAIT YEAR*BAIT	**1163.7**	**1166.5**	**1159.7**				

Table 9. The absolute standardized and nominal index of abundance for blacknose shark with the associated coefficients of variation (CV) and number of sets observed (N).

Year	Standardized index	CV	N	Nominal index	CV
1994	18.03	0.42	102	42.90	6.02
1995	39.39	0.22	162	55.81	3.25
1996	41.60	0.23	126	85.15	3.20
1997	12.23	0.43	80	7.93	3.06
1998	35.59	0.31	110	34.92	3.17
1999	67.02	0.34	99	46.61	2.64
2000	129.07	0.37	64	297.83	5.09
2001	24.65	0.56	77	29.60	6.31
2002	81.41	0.38	132	86.20	2.58
2003	65.83	0.40	171	47.58	3.08
2004	56.40	0.39	120	47.02	3.11
2005	137.15	0.37	127	182.55	4.04
2006	148.40	0.39	117	214.72	2.73
2007	85.38	0.48	62	157.91	4.50
2008	98.31	0.45	61	50.23	2.10
2009	23.63	0.49	114	16.92	3.25

Figure 9. Nominal (obscpue) and standardized (STDCPUE) indices of abundance for blacknose shark. The dashed lines are the 95% confidence limits (LCL, UCL) for the standardized index. Each index has been divided by the maximum of the index.

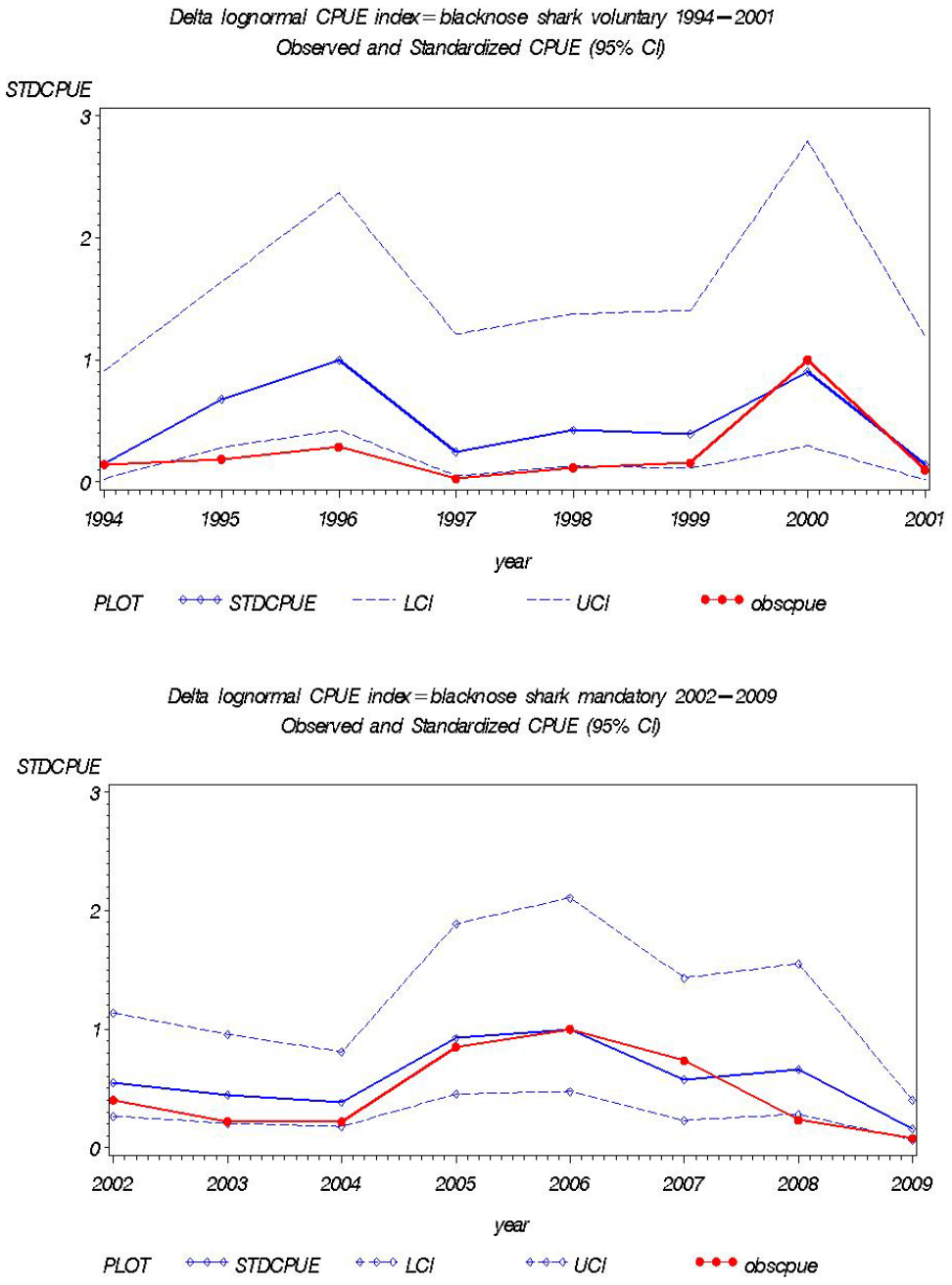
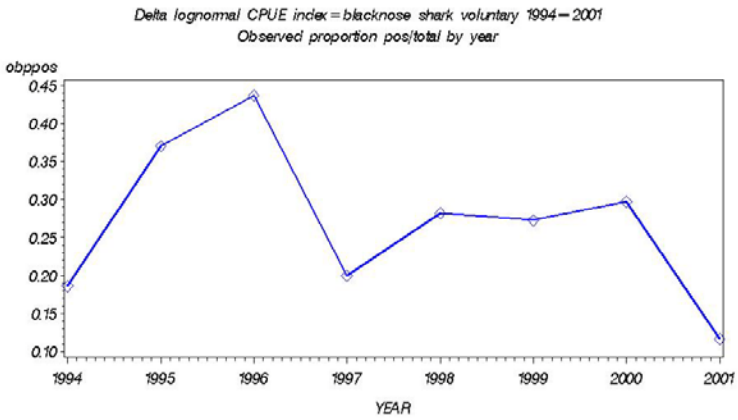
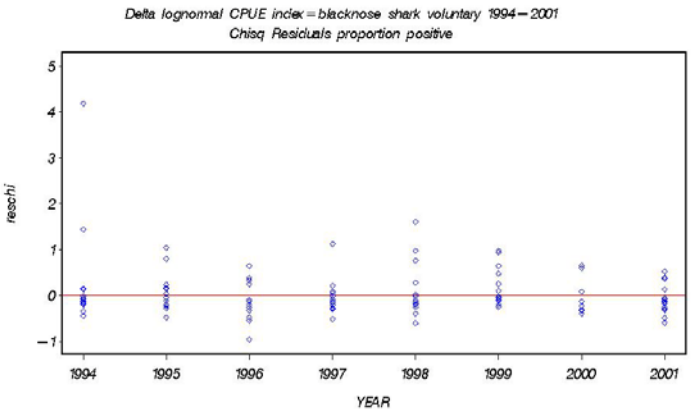
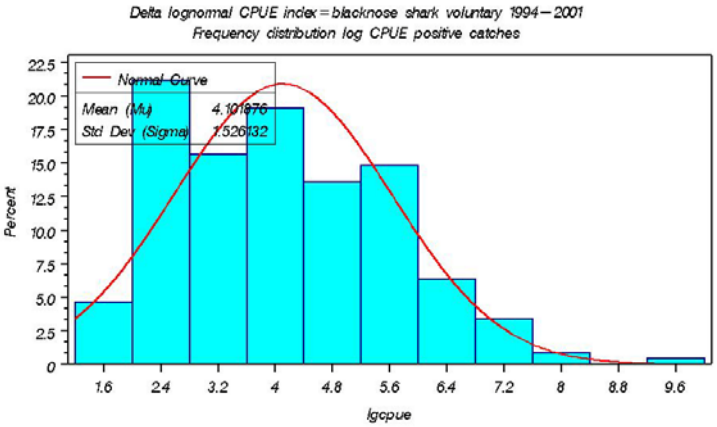


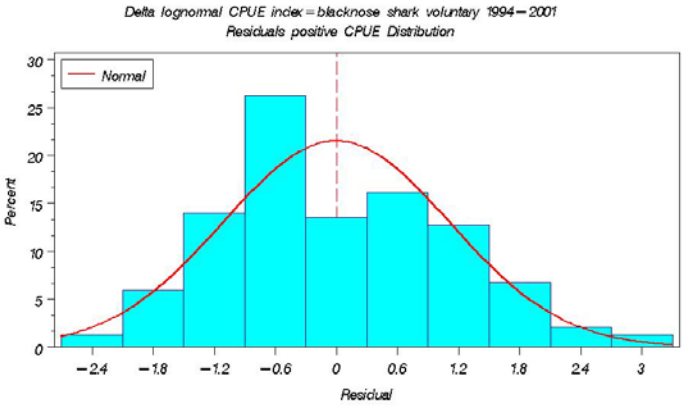
Figure 10. Diagnostic plots of the frequency distribution of residuals, quantile-quantile plots, and distribution of residuals by year from the lognormal model for blacknose shark.

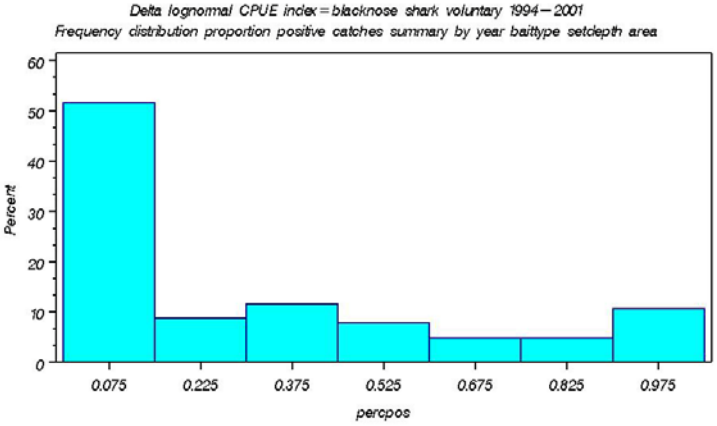


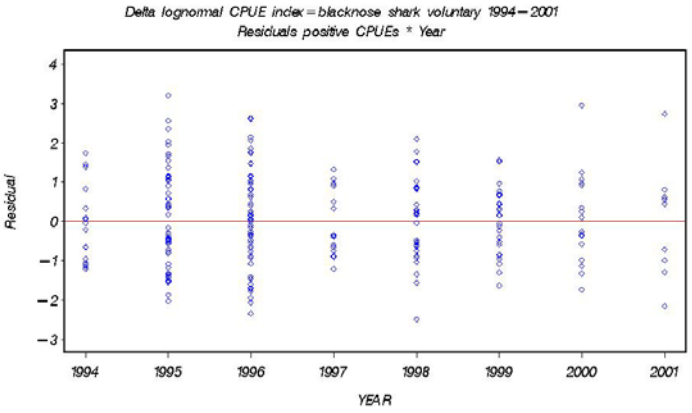
If prop pos=[1 or 0] Binomial model will not estimate a value for that year!



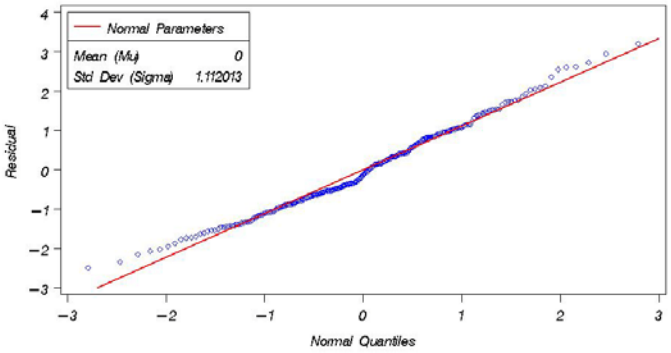




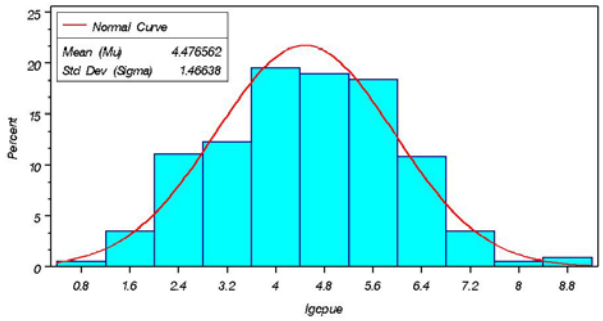




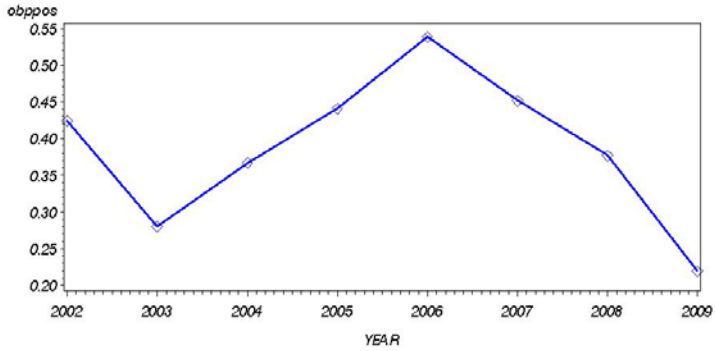
Delta lognormal CPUE index=blacknose shark voluntary 1994–2001
QQplot residuals Positive CPUE rates



Delta lognormal CPUE index=blacknose shark mandatory 2002–2009
Frequency distribution log CPUE positive catches

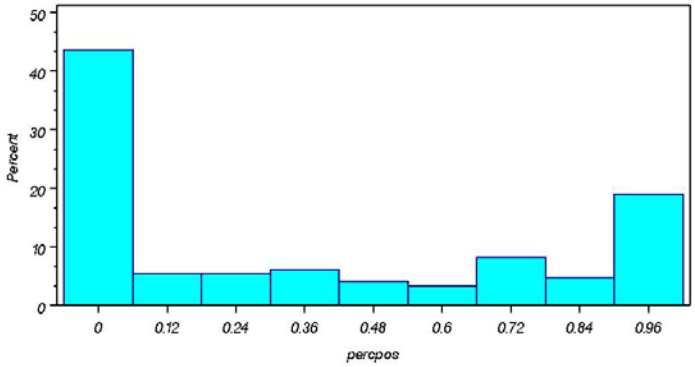


Delta lognormal CPUE index=blacknose shark mandatory 2002–2009
Observed proportion pos/total by year

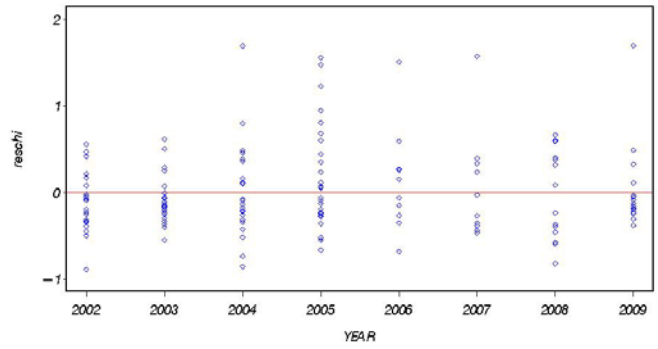


If prop pos=[1 or 0] Binomial model will not estimate a value for that year!

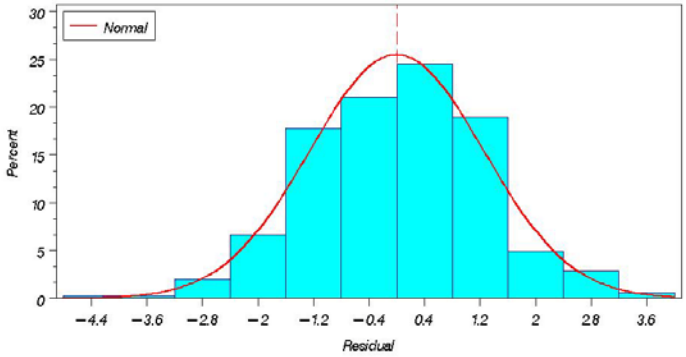
Delta lognormal CPUE index=blacknose shark mandatory 2002–2009
Frequency distribution proportion positive catches summary by year area setdepth baittype

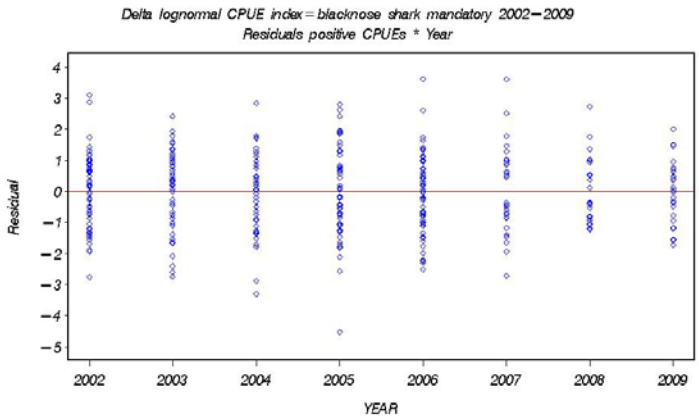


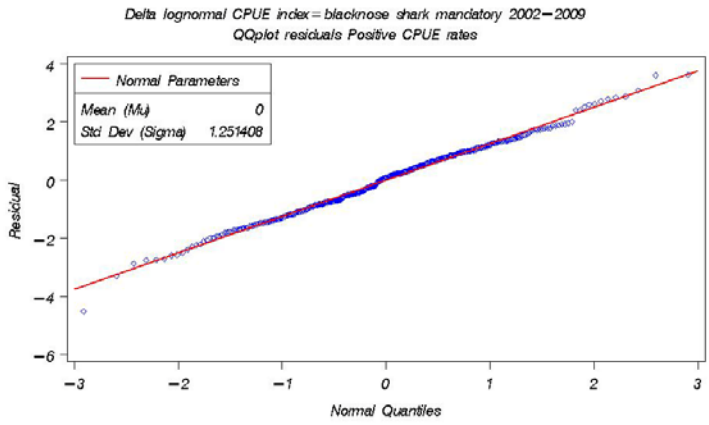
Delta lognormal CPUE index=blacknose shark mandatory 2002–2009
Chisq Residuals proportion positive



Delta lognormal CPUE index=blacknose shark mandatory 2002–2009
Residuals positive CPUE Distribution







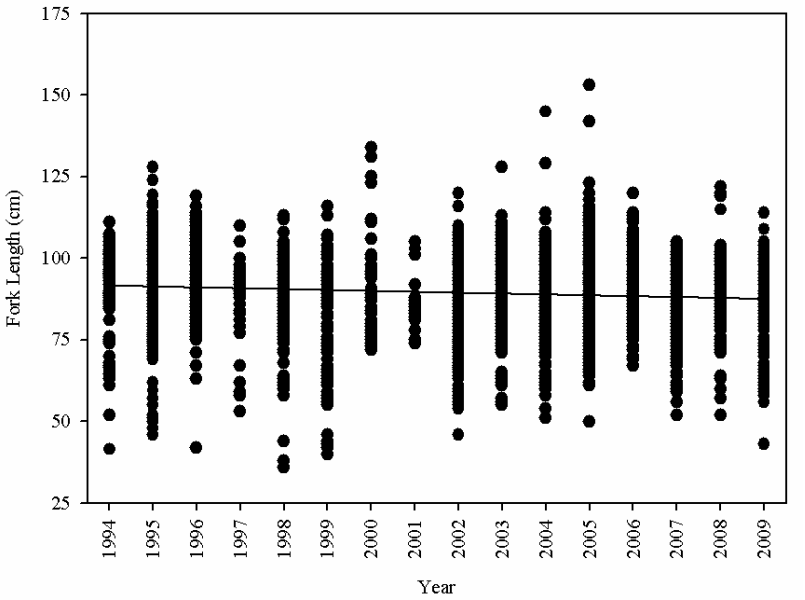
Trends in size

Linear regressions fit to fork lengths of sharks caught from the observer program indicated a declining trend ($p<0.0001$, $r^2=0.01$) in length over time. Average size decreased between 1994 and 2009 (Figure 11) (Table 10).

Table 10. Average blacknose shark lengths by year from observations from 1994 through 2009.

Year	Average Size (cm FL)	Standard deviation (cm)	Sample size (n)
1994	91.94	11.61	132
1995	93.07	11.93	406
1996	93.24	8.33	414
1997	84.03	14.96	38
1998	87.70	12.38	197
1999	83.70	17.59	116
2000	87.13	13.62	76
2001	85.37	7.39	27
2002	85.34	11.76	454
2003	91.33	9.21	476
2004	86.78	10.44	346
2005	90.06	11.10	461
2006	92.82	8.57	330
2007	88.93	8.90	412
2008	89.04	10.37	168
2009	84.06	12.42	248

Figure 11. Blacknose shark lengths by year from observations from 1994 through 2009.



Acknowledgements

We thank all the observers since inception of the programs for collecting data sometimes during somewhat arduous conditions.

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