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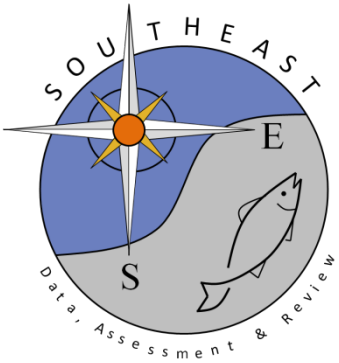

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Introduction

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, Hale et al. 2010, and Hale et al. 2011). Currently 208 U.S. fishers are permitted to target sharks (excluding dogfish) in the Atlantic Ocean and Gulf of Mexico, and an additional 253 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). These 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. Since 2008, only commercial shark fishers participating in the shark 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. (2011). With the introduction of the 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"
  1994-2010

- "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 = January-March
  Spring = April-June
  Summer = July-September
  Fall = October-December

●"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

●"Hook type": the hook that was used by the majority of the set
    Large hook (> size 13 hook)
    Medium hook (size 10-13 hook)
    Small hook (< size 10 hook)
    Hook size undefined

●"Bait type": the bait that was used by the majority of the set
    Shark or ray (Elasmobranchii)
    Herring (Clupeidae) or mullet (Mugilidae)
    Tuna or mackeral (Scombridae)
    Other teleosts (non-Clupeidae, Mugilidae or Scombridae)
    Other (undefined or multiple bait types)

● Research
    Yes (a set conducted under the shark research fishery)
    No (a set not conducted under the shark research fishery)

● Soak time (continuous variable)
    Time from the first hook entering the water to the first hook retrieved

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 10,000 hooks

$$CPUE = log\ [(sharks\ kept+sharks\ released/10{,}000\ hooks)]$$

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 provided 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

The final bottom longline dataset analyzed contained 824 sets (Figure 1). Of those sets, blacktip sharks were reported caught on 56.9% of sets. The stepwise construction of the model is summarized in Table 1 and the index statistics can be found in Table 2. Table 3 provides a table of the frequency of observations by factor and level. The standardized abundance index is shown in Figure 2 and the diagnostic plots assessing the fit of the models were deemed acceptable (Figure 3). The length distribution (cm FL) of sharks caught by year and sex is shown in Figure 4 and average length by year is in Table 4.

Table 1. Analysis of deviance of explanatory variables for the binomial and lognormal generalized linear and mixed model formulations of the proportion of positive and positive catches for blacktip sharks. Final models selected are in bold.

Proportion positive-Binomial error distribution						
FACTOR	**DEVIANCE/DF**	**%DIFF**	**DELTA%**	**CHISQUARE**	**PR>CHI**	**AIC**
NULL	1.384					
YEAR	1.241	10.320	10.320			989
YEAR+						
DEPTH	1.120	19.079	8.759	95.84	<.0001	901
HOOK TYPE	1.218	11.946		20.84	0.0001	975
BAIT TYPE	1.233	10.920		11.24	0.024	986
SRF	1.233	10.869		7.04	0.008	984
SEASON	1.237	10.616		6.85	0.077	989
SOAK	1.242	10.212		0.09	0.7652	991
TIME	1.243	10.205		0	0.9635	991
YEAR+DEPTH+						
HOOK TYPE	1.1055	20.106	1.026	14.07	0.0028	892
BAIT TYPE	1.115	19.433		8.16	0.086	899
SRF	1.118	19.209		2.51	0.113	899
MIXED MODEL	**AIC**					
YEAR+DEPTH+HOOK TYPE	305.600					
YEAR+DEPTH+HOOK TYPE YEAR*DEPTH	305.600					
YEAR+DEPTH+HOOK TYPE YEAR*HOOK TYPE	**294.200**					

Proportion positive-Lognormal error distribution						
FACTOR	**DEVIANCE/DF**	**%DIFF**	**DELTA%**	**CHISQUARE**	**PR>CHI**	**AIC**
NULL	2.027					
YEAR	1.844	9.013	9.013	62.2	<.0001	1732
YEAR+						
DEPTH	1.774	12.477	3.463	22.41	<.0001	1716
HOOK TYPE	1.794	11.519		17	0.0007	1721
BAIT TYPE	1.826	9.911		9.09	0.059	1731
SEASON	1.843	9.102		3.61	0.3062	1735
TIME	1.846	8.944		0.68	0.4098	1734
SOAK	1.848	8.826		1.01	0.3156	1731
SRF	1.848	8.821		0	0.9979	1734
YEAR+DEPTH+						
HOOK TYPE	1.7197	15.160	2.684	18.62	0.0003	1703
MIXED MODEL	**AIC**					
YEAR+DEPTH+HOOK TYPE	1686.1					
YEAR+DEPTH+HOOK TYPE YEAR*DEPTH	1683.2					
YEAR+DEPTH+HOOK TYPE YEAR*HOOK TYPE	**1664.5**					

Table 2. The standardized and nominal index (number of sharks per net hour) of absolute abundance, and coefficients of variation (CV) for all blacktip sharks from both surveys. N = number of sets.

YEAR	N	ABSOLUTE STANDARDIZED INDEX	CV	ABSOLUTE NOMINAL INDEX	CV
1994	47	23.39	0.40	20.33	0.46
1995	53	65.50	0.28	78.59	0.23
1996	40	56.05	0.35	77.89	0.25
1997	26	36.87	0.81	57.53	0.52
1998	38	107.78	0.56	189.39	0.32
1999	31	135.01	0.46	138.64	0.45
2000					
2001	23	1.94	1.75	0.68	4.97
2002	64	235.93	0.24	188.39	0.31
2003	81	271.19	0.20	231.82	0.23
2004	70	299.25	0.23	242.79	0.28
2005	75	155.92	0.26	192.86	0.21
2006	68	313.44	0.30	397.51	0.24
2007	28	253.13	0.30	293.39	0.26
2008	35	191.27	0.31	129.38	0.46
2009	76	229.66	0.29	148.63	0.45
2010	69	154.57	0.29	190.39	0.24

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

FACTOR	LEVEL	FREQUENCY OF TOTAL
Year	1994	5.7
	1995	6.4
	1996	4.9
	1997	3.2
	1998	4.6
	1999	3.8
	2000	0.0
	2001	2.8
	2002	7.8
	2003	9.8
	2004	8.5
	2005	9.1
	2006	8.3
	2007	3.4
	2008	4.2
	2009	9.2
	2010	8.4
Research Fishery	Yes	19.8
	No	80.2
Season	Fall	8.0
	Spring	12.0
	Summer	44.9
	Winter	35.1
Time of Day	Day	18.9
	Night	81.1
Hook Type	Large	69.2
	Medium	6.9
	Other	21.5
	Small	2.4
Bait type	Clupeids+Mugilids	1.7
	Elasmobranchs	7.8
	Other	46.0
	Other Teleosts	16.9
	Scombrids	27.7
Set Depth	0-100	49.3
	100-200	21.7
	200-300	18.8
	300>	10.1

Table 4. Average blacktip shark fork lengths by year and sex from the shark directed bottom longline fishery observations from 1994 through 2010 (n = 6507). n/a=no observations of that species for that year.

Year	n	Mean Female FL (cm)	SE	n	Mean Male FL (cm)	SE	n	Mean Combined FL (cm)	SE
1994	47	109.5	0.9	44	109.1	2.1	91	107.9	1.8
1995	187	107.1	1.5	176	101.6	1.2	363	104.5	1.0
1996	84	107.7	2.6	106	106.8	1.9	190	107.2	1.6
1997	5	123.0	9.9	90	118.9	1.2	95	119.1	1.3
1998	247	122.2	1.0	52	110.2	1.4	299	120.1	0.9
1999	219	128.9	0.6	38	116.7	1.7	257	127.1	0.6
2000	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a
2001	n/a	n/a	n/a	1	129.0	0.0	1	129.0	0.0
2002	280	133.3	0.9	261	118.7	0.8	541	126.3	0.7
2003	489	115.5	0.9	698	106.7	0.6	1187	110.4	0.5
2004	392	123.0	0.9	576	110.6	0.5	968	115.6	0.5
2005	270	126.4	1.0	149	114.5	1.1	419	122.1	0.8
2006	428	117.0	0.8	413	112.9	0.6	841	115.0	0.5
2007	151	124.3	1.3	356	111.3	0.8	507	115.2	0.7
2008	149	129.2	0.8	81	112.9	1.4	230	123.4	0.9
2009	60	129.2	2.3	117	125.8	0.9	177	126.9	1.0
2010	138	129.0	1.4	203	123.3	0.9	341	125.6	0.8

Figure 1. Distribution of observed fishing effort in the Gulf of Mexico for the directed shark bottom longline fishery 1994-2010.

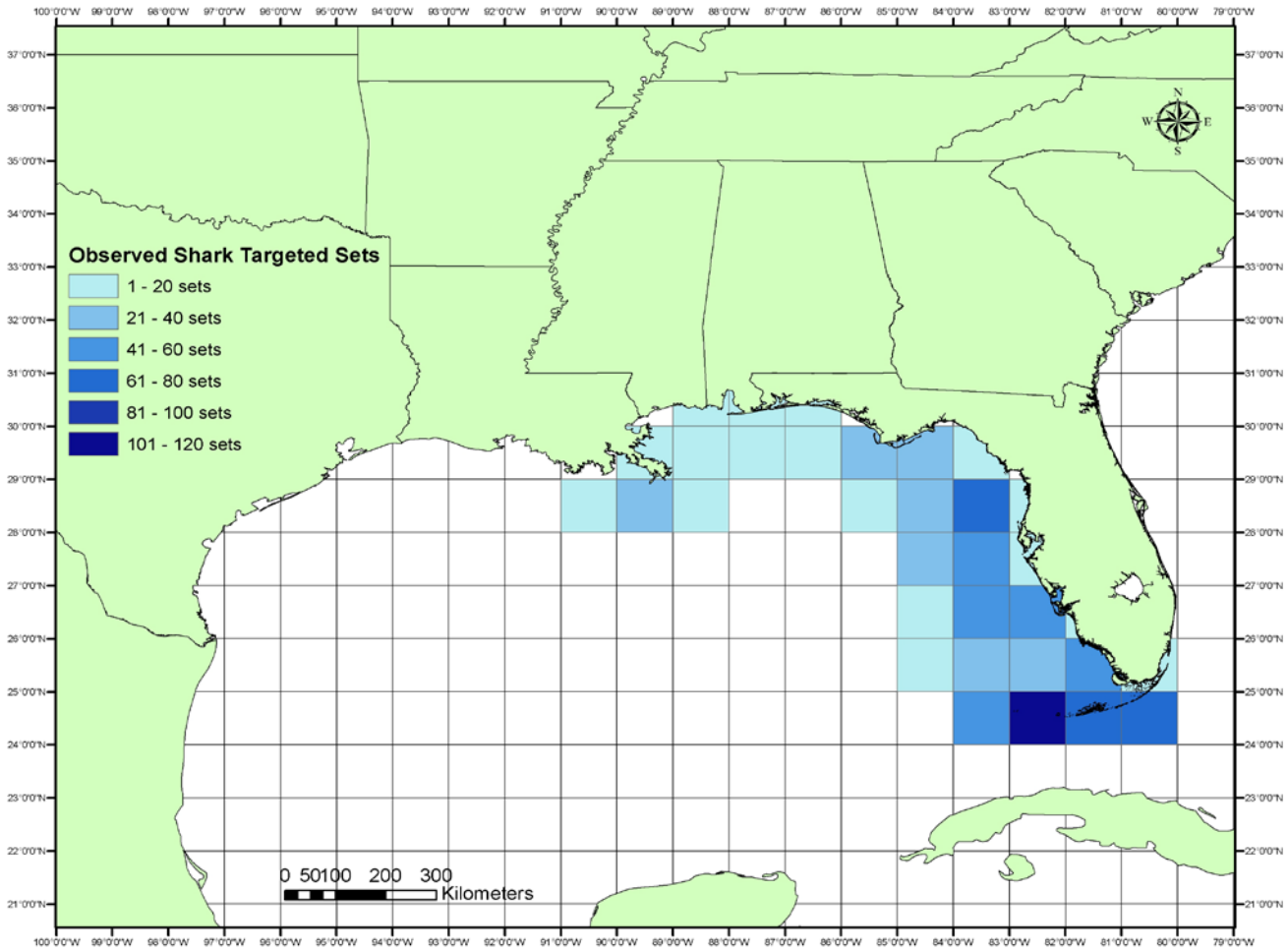
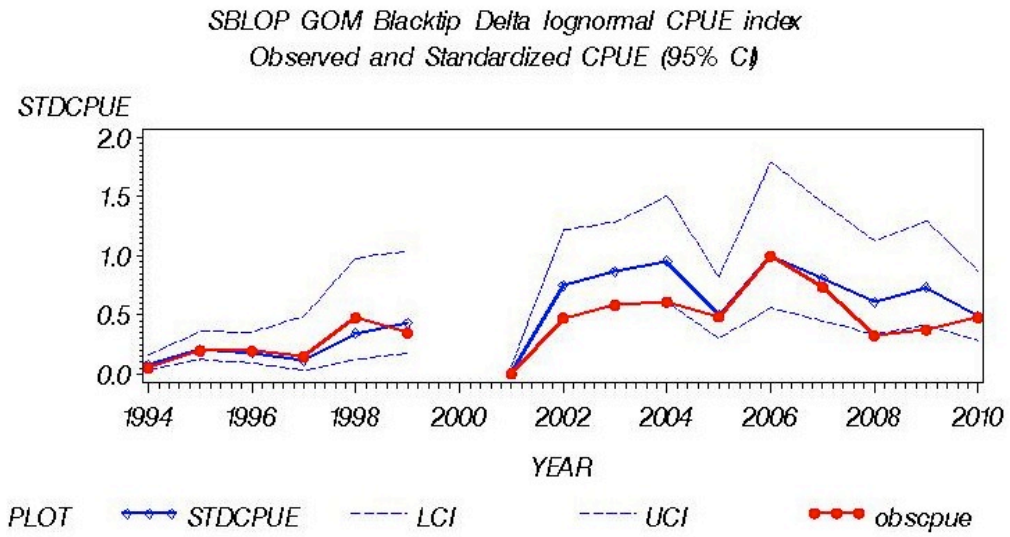


Figure 2. Nominal (obscpue) and standardized (STDCPUE) indices of abundance for blacktip sharks from the Shark Bottom Longline Survey. The dashed lines are the 95% confidence limits (LCL, UCL) for the standardized index. Each index has been divided by the maximum of the index. For comparison, the index determined at SEDAR11 is provided to demonstrate continuity.



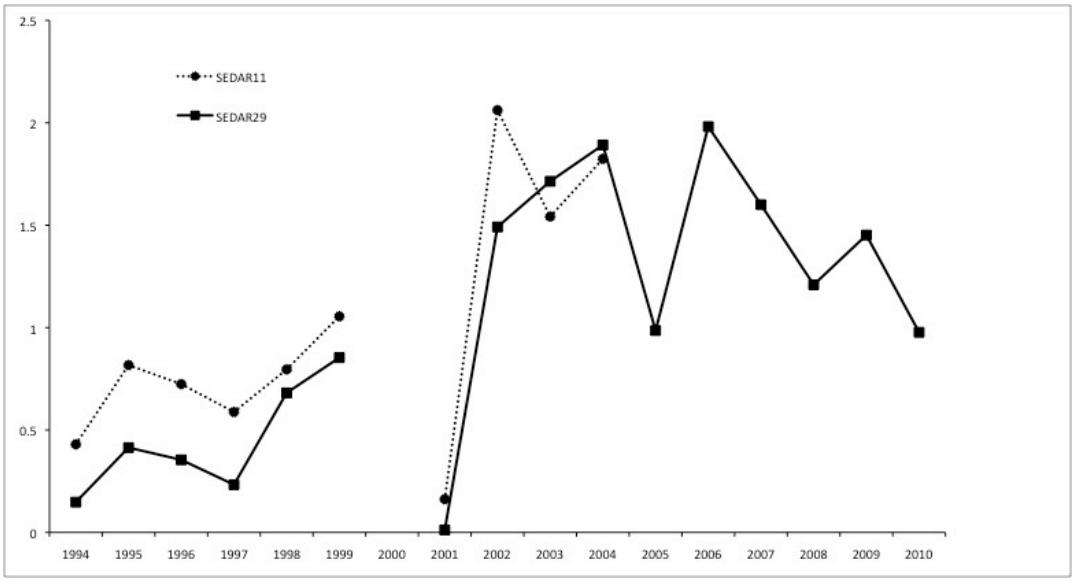
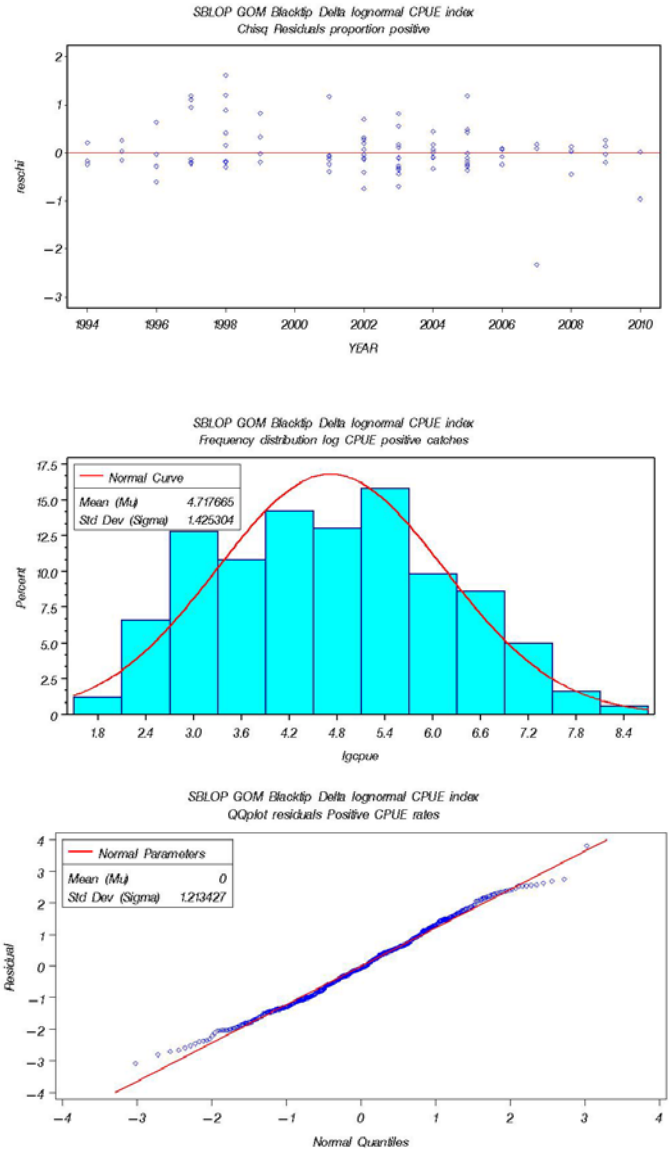
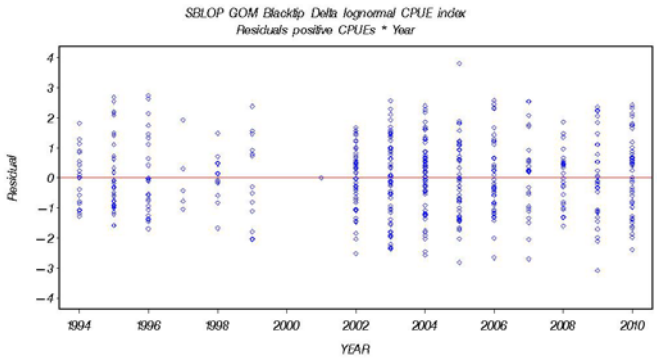


Figure 3. Diagnostic plots of the frequency distribution of residuals, quantile-quantile plots, and distribution of residuals by year.




SBLOP GOM Blacktip Delta lognormal CPUE index
Residuals positive CPUEs * Year
Residual
YEAR
4
3
2
1
0
−1
−2
−3
−4
1994
1996
1998
2000
2002
2004
2006
2008
2010

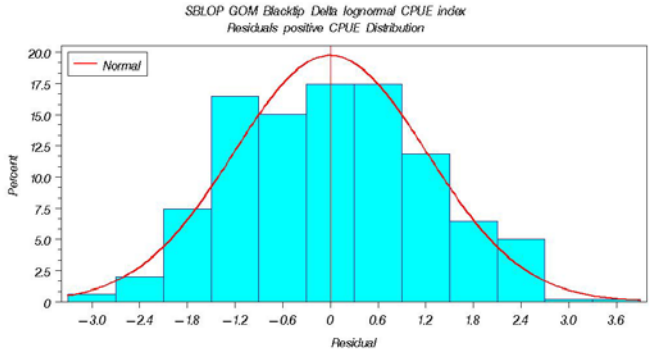
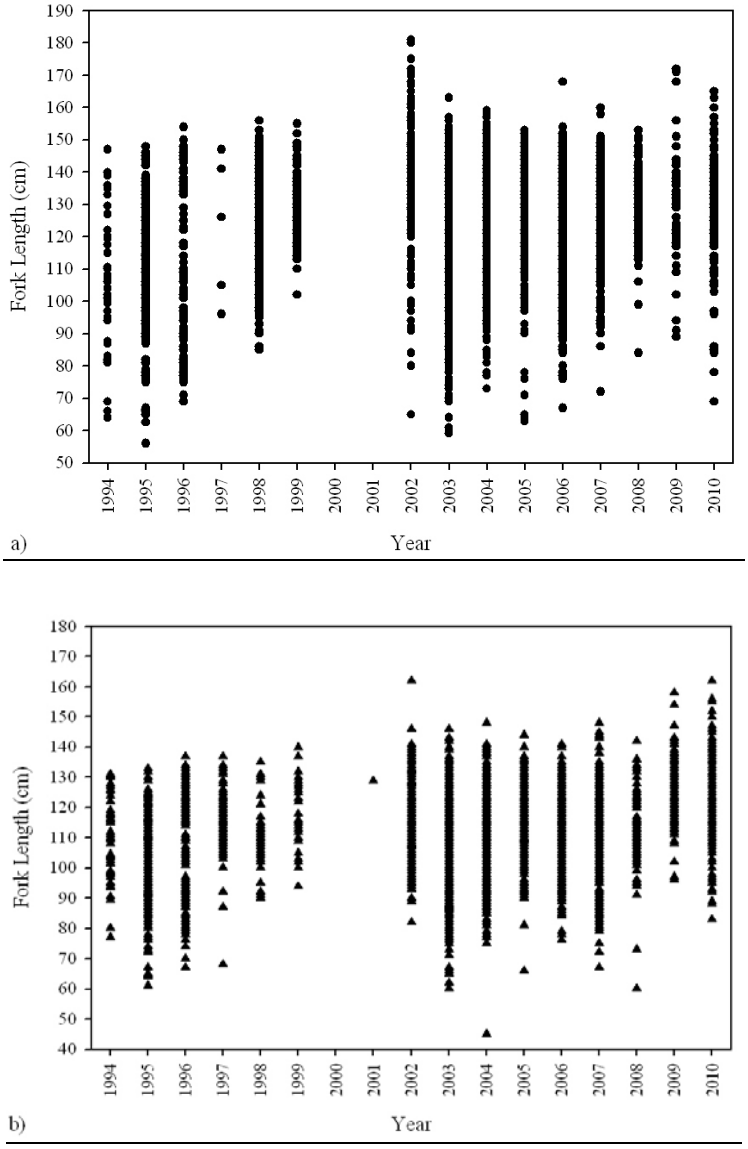

SBLOP GOM Blacktip Delta lognormal CPUE index
Residuals positive CPUE Distribution
Normal
Percent
Residual
20.0
17.5
15.0
12.5
10.0
7.5
5.0
2.5
0
−3.0
−2.4
−1.8
−1.2
−0.6
0
0.6
1.2
1.8
2.4
3.0
3.6

Figure 4. Observed fork lengths (FL) by year for all blacktip sharks captured by year for a) females (n = 3146) and b) males (n = 3361)



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