Relative abundance of blacktip shark, *Carcharhinus limbatus*, from the eastern Gulf of Mexico

John Carlson, Dana Bethea, John Tyminski, and Robert Hueter

SEDAR29-WP-01

Date Submitted: 26 January 2012
Updated: 21 February 2012
Updated: 30 March 2012

Relative abundance of blacktip shark, *Carcharhinus limbatus*, from the eastern Gulf of Mexico

John Carlson
National Marine Fisheries Service, Southeast Fisheries Science Center,
3500 Delwood Beach Rd. Panama City, FL 32408
John.Carlson@noaa.gov

Dana Bethea
National Marine Fisheries Service, Southeast Fisheries Science Center,
3500 Delwood Beach Rd. Panama City, FL 32408

John Tyminski
Center for Shark Research
Mote Marine Laboratory
1600 Ken Thompson Parkway
Sarasota, FL 34236

Robert Hueter
Center for Shark Research
Mote Marine Laboratory
1600 Ken Thompson Parkway
Sarasota, FL 34236

SEDAR 29-WP-01

INTRODUCTION

Two fishery-independent surveys of coastal shark populations have taken place since 1995 in the eastern Gulf of Mexico. One survey conducted by National Marine Fisheries Service (NMFS)-Panama City Laboratory is designed to examine the distribution and abundance of juvenile sharks in coastal areas of the northeastern Gulf of Mexico. The ultimate intent of this survey is to continue to describe and further refine shark essential fish habitat as mandated by the Magnuson-Steven Fishery Conservation and Management. The Center for Shark Research (CSR) at Mote Marine Laboratory has been conducting routine surveys of juvenile sharks in Florida Gulf coast nursery areas since 1995 as part of a NMFS/MARFIN-funded project on shark nurseries to assess Florida's coastal areas as nurseries specifically for the blacktip shark (*Carcharhinus limbatus*). The project also documented nursery areas of other shark species, quantified relative abundance of juvenile blacktips and other shark species, determined bycatch mortality of these small sharks and associated fishes in gill net fishing gear, and conducted basic biological studies of shark distribution, feeding, growth and reproduction in the Florida Gulf. Building upon the CSR's MARFIN study, research funded primarily through NMFS Highly Migratory Species (HMS) Division extended the CSR shark nursery studies in the Gulf of Mexico through 2004, allowing a relatively continuous sampling of juvenile sharks in these nurseries in all years except 1998.

This paper determines a relative abundance index for juvenile blacktip sharks from both the Panama City and Mote Marine Laboratory surveys. In addition, data from both surveys were combined in an attempt to provide a single relative index of abundance for juvenile blacktip sharks for the eastern Gulf of Mexico.

MATERIAL AND METHODS

Panama City Laboratory Field Data Collection

A 186-m long gill net consisting of six different mesh size panels was utilized for sampling. Stretched mesh sizes (SM) ranged from 8.9 cm (3.5") to 14.0 cm (5.5") in steps of 1.27 cm (0.5"), with an additional size of 20.3 cm (8.0"). Panel depths when fishing were 3.1 m. Webbing for all panels, except for 20.3-cm, was of clear monofilament, double knotted and double selvaged. The 20.3-cm SM webbing was made of #28 multifilament nylon, single knotted, and double selvage. In 2005, a panel of net with 7.6 cm (3.0") mesh size was added to the sampling gear and the 20.3 cm mesh panel was removed. Previous analysis has found the removal of this mesh panel did not affect shark catch rates.

Surveys were conducted monthly from April-October, occasionally March-November. The sampling gear was set at fixed stations or randomly set within each area based on depth strata and GPS location. The nets were checked and cleared of catch or pulled and reset every 1.0-2.0 hr. Sharks were measured to the nearest cm for body lengths (precaudal, fork, total, and stretch total length) and data for sex and life history stage (neonate, young-of-the-year, juvenile, adult) were recorded. Sharks that were in poor condition were sacrificed for life history studies and those in good condition were tagged and released. Environmental data were collected prior to

sampling. Mid-water temperature (°C), salinity (ppt), and dissolved oxygen (mg l^{-1}) was measured with a YSI Model 55 oxygen meter and light transmission (cm) was determined using a secchi disk. Further details can be found in Carlson and Brusher (1999).

Mote Marine Laboratory Field Data Collection

Monthly, random stratified, fishery-independent sampling by gill net was conducted in the three Florida Gulf bays from March through October (with sampling in summer months only during 1999-2004) in all years except 1998. In each area, two geographically fixed 10 km^2 grids were regularly sampled based upon previous exploratory surveys that revealed subareas with relatively high CPUE of juvenile blacktip sharks. For quantitative assessment of relative abundance, standardized sets were conducted each month in five of the ten 1 x 1 km blocks for each grid. Sets were made using 0.52 mm monofilament, 11.8 cm stretch mesh, 366 x 3 m weighted gill nets, used because of their relatively high selectivity for small sharks and relatively low bycatch of other species. The net was allowed to soak for one hour before being retrieved. All shark catch was identified, sexed, categorized by stage of maturity (neonate, young-of-the-year, older juvenile, or mature), measured and weighed, and live sharks were tagged and released. Physical data including depth, tide, salinity, temperature, dissolved oxygen, bottom type, and weather were collected for each set to characterize shark nursery habitat in the three areas.

Index Development

While these surveys were fishery-independent and factors were generally controlled, we applied a generalized linear model to correct for factors that could have influenced abundance. Several categorical variables were constructed for analysis of the survey data:

"Year" (16 levels): 1995-2010

"Area" (7 levels): locations of gillnet set (Figure 1).

"SetBegin" (4 levels):
Dawn=0401-1000 hrs
Day=1001-1600 hrs
Dusk=1601-2200 hrs
Night=2201-0400 hrs

"Survey" (2 levels): Laboratory conducting the survey

"Season" (3 levels):
Spring=Mar-May
Summer=Jun-Aug
Fall=Sep-Nov

"Setdepth" (2 levels):
Shallow=less than 5 meters
Deep=greater than 5 meters

"Bottom type" (4 levels)
Mud, Sand, Seagrass, Shell

Indices of abundance were estimated following the Delta method (Lo et al., 1992) by modeling the probability of the non-zero catch assuming a type-3 model with a binomial error distribution and a logit link. The distribution of the positive shark catches was modeled assuming a lognormal distribution. Catch per unit effort was the number of blacktip sharks caught per hour.

Following Ortiz and Arocha (2004), factors most likely to influence abundance were evaluated in a forward stepwise fashion. 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 models. This allows the estimation of the annual indices, which is the main objective of the standardization process, but also accounts for the variability associated with year-interactions. After selecting the set of factors for each error distribution, all factors that included the factor year were treated as random interactions (Ortiz and Arocha, 2004). We applied a Generalized Linear Mixed Modeling (GLMM), approach because these models can predict CPUEs for un-fished fishing cells based on the estimated effects of the explanatory variables as long as these cells were fished in some of the years. The standardized CPUE values for the Delta models were calculated as the product of the expected probability of a non-zero catch and the expected conditional catch rate for sets that had a non- zero catch. The expected probability and expected conditional catch rate were the least square means of the factor year from each of the two analyses that constitute an analysis using the Delta model approach (Lo et al., 1992; Stefansson, 1996). All 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).

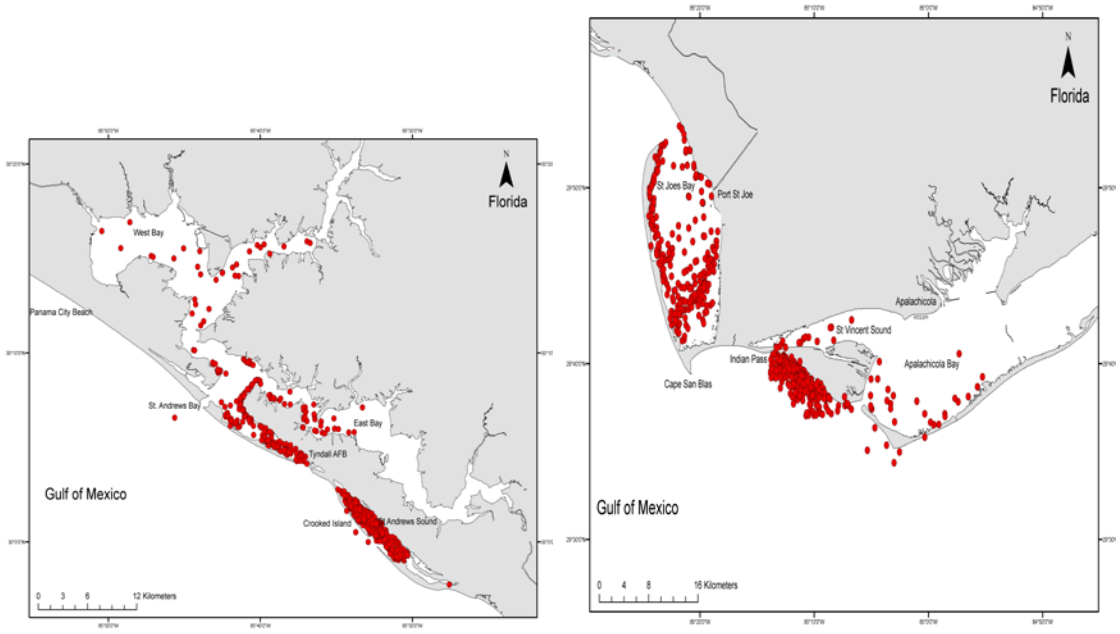
Final models were selected based on Akaike Information Criteria (AIC). Models of positive catches were checked for appropriate fit and diagnostics by examining the residuals plotted against the fitted values to check for systematic departures from the assumptions underlying the error distribution; the absolute values of the residuals plotted against the fitted values as a check of the assumed variance function; and the dependent variable was plotted against the linear predictor function as a check of the assumed link function (McCullagh and Nelder, 1989).

RESULTS AND DISCUSSION

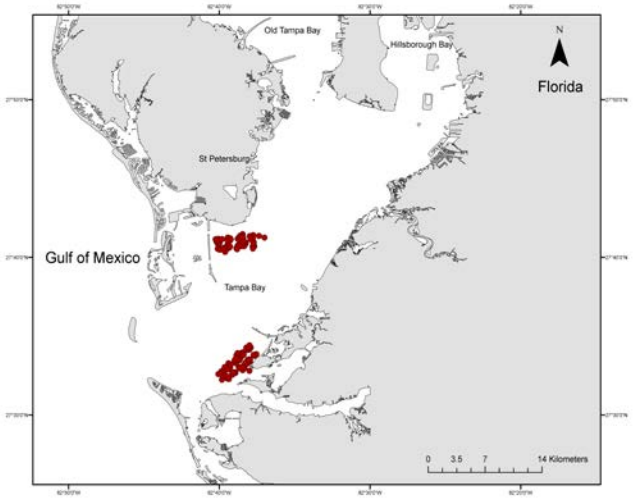
A total of 2380 gillnet sets have been made throughout all areas since 1995. By survey, 1410 sets were made by the Panama City Laboratory (Figure1a) and 970 by Mote Marine Laboratory (Figure 1b). The majority of individuals captured were juveniles and the length distribution did not change significantly over the survey period (Figure 2).

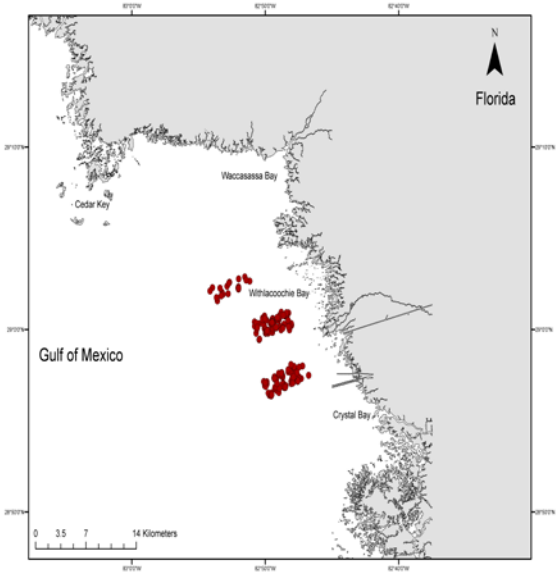
Figure 1. Location of study sites in the eastern Gulf of Mexico. Locations of sets of fishing gear are represented by dots.

a) Panama City Laboratory Field Data Collection



b) Mote Marine Laboratory Field Data Collection





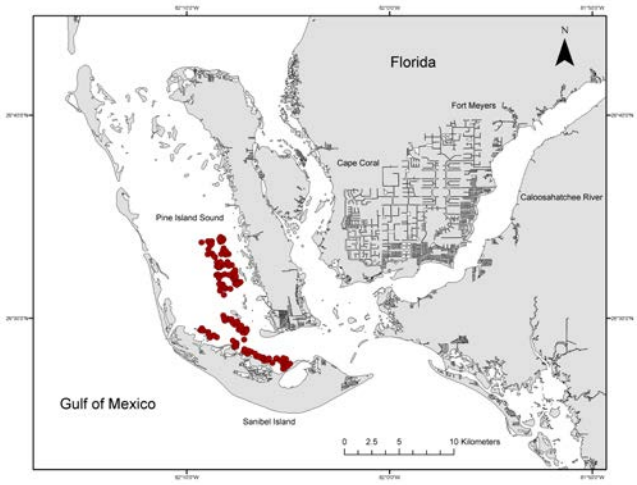
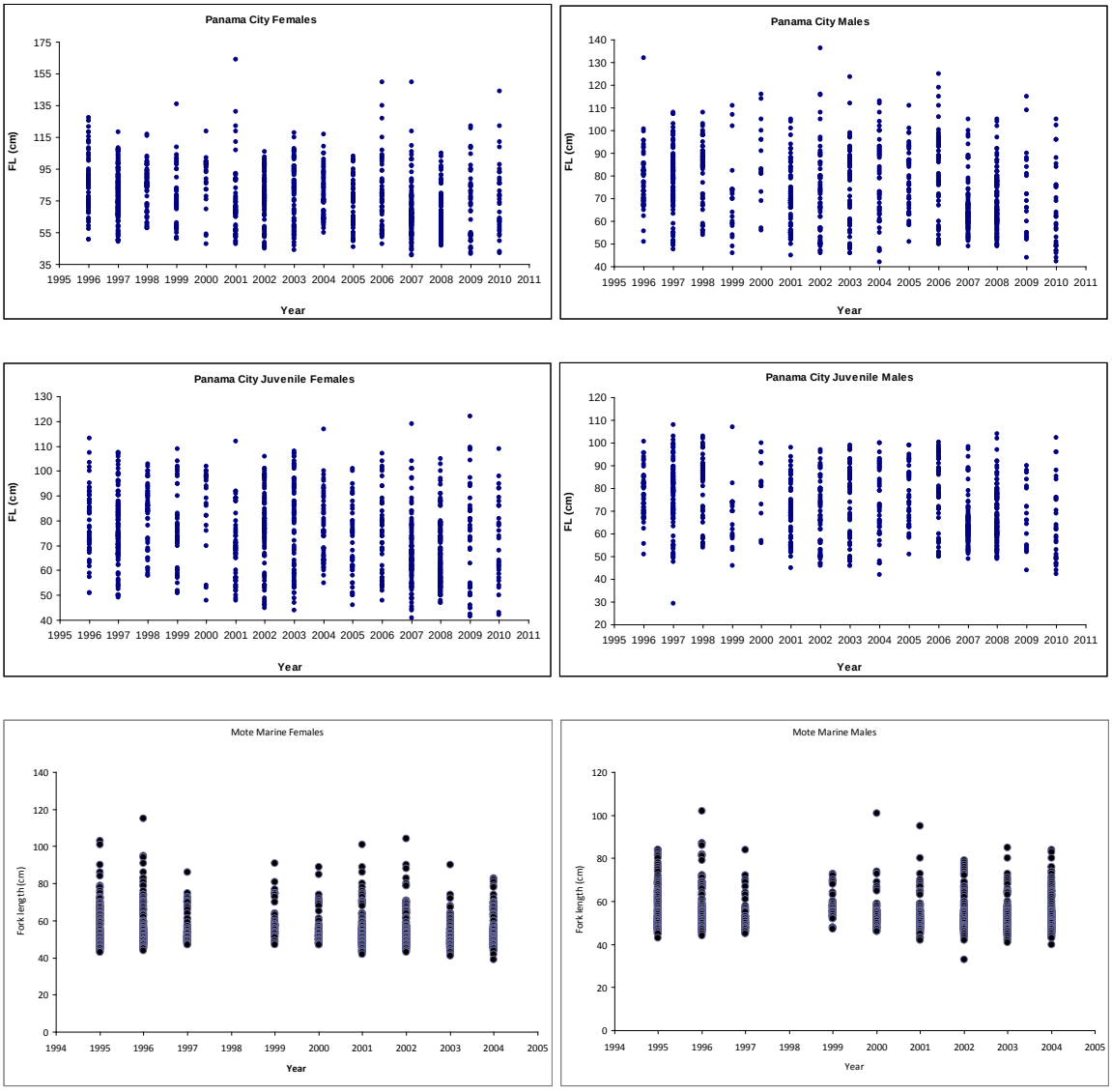


Figure 2. Observed fork lengths (FL) by year for all blacktip sharks captured and juvenile blacktips sharks by sex and survey.



All blacktip sharks combined

A time series of abundance was determined for all blacktip sharks captured regardless of size or maturity state for the combined surveys. The proportion of positive sets (at least one blacktip shark was caught) was 34.8%. 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 3 and the diagnostic plots assessing the fit of the models were deemed acceptable (Figure 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 all blacktip sharks for combined surveys. Final models selected are in bold.

Proportion positive-Binomial error distribution					
FACTOR	**DEVIANCE/DF**	**%DIFF**	**DELTA%**	**CHISQUARE**	**PR>CHI**
NULL	1.7632				
YEAR	1.7275	2.025	2.025	53.28	<.0001
YEAR+					
AREA	1.2852	27.110	25.085	339.83	<.0001
BOTTOMTYPE	1.51	14.360		167.87	<.0001
SEASON	1.6835	4.520		36.42	<.0001
SETDEPTH	1.705	3.324		18.9	<.0001
SURVEY	1.7094	3.051		15.31	<.0001
SETBEGIN	1.7224	2.314		8.97	0.0298
YEAR+AREA+					
SEASON	1.252	28.993	3.908	27.25	<.0001
BOTTOMTYPE	1.2694	28.006		15.63	0.0013
SETBEGIN	1.2822	27.280		6.13	0.1054
SURVEY	1.2852	27.110		0	
SETDEPTH	1.2863	27.047		0.52	0.4725
YEAR+AREA+SEASON+					
BOTTOMTYPE	1.2358	29.912	0.919	15.79	0.0013
MIXED MODEL	**AIC**				
YEAR+AREA+SEASON	**649.400**				
YEAR+AREA+SEASON YEAR*SEASON	650.800				
YEAR+AREA+SEASON YEAR*AREA	649.400				

Proportion positive-Lognormal error distribution					
FACTOR	**DEVIANCE/DF**	**%DIFF**	**DELTA%**	**CHISQUARE**	**PR>CHI**
NULL	1.1663				
YEAR	1.1431	1.989	1.989	31.78	0.0069
YEAR+					
AREA	1.0113	13.290	11.301	107.61	<.0001
SURVEY	1.0858	6.902		43.63	<.0001
SETDEPTH	1.1023	5.487		31.12	<.0001
BOTTOMTYPE	1.1169	4.236		21.28	<.0001
SEASON	1.1371	2.504		6.41	0.0405
SETBEGIN	1.1439	1.921		2.51	0.4733
YEAR+AREA+					
SEASON	1.0111	13.307	0.017	2.19	0.3347
SURVEY	1.0113	13.290		0	.
BOTTOMTYPE	1.0123	13.204		1.22	0.5435
SETDEPTH	1.0125	13.187		0	0.9849
MIXED MODEL	**AIC**				
YEAR+AREA	2382.3				
YEAR+AREA YEAR*AREA	**2372.7**				

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
1995	250	0.799	0.28	1.154	0.19
1996	186	0.780	0.30	1.685	0.14
1997	135	0.558	0.32	0.863	0.21
1998	68	0.816	0.52	0.261	1.61
1999	101	0.986	0.29	1.056	0.27
2000	114	1.138	0.29	1.298	0.25
2001	172	1.496	0.24	2.045	0.17
2002	230	1.359	0.24	1.745	0.18
2003	230	1.180	0.24	1.494	0.19
2004	197	1.635	0.23	2.454	0.15
2005	149	1.237	0.35	0.515	0.83
2006	145	1.355	0.32	0.547	0.78
2007	143	1.703	0.32	1.063	0.51
2008	128	1.693	0.31	1.320	0.39
2009	82	1.006	0.40	0.583	0.69
2010	50	1.381	0.42	0.668	0.88

Figure 3. Nominal (obscpue) and standardized (STDCPUE) indices of abundance for all blacktip sharks for both surveys. 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

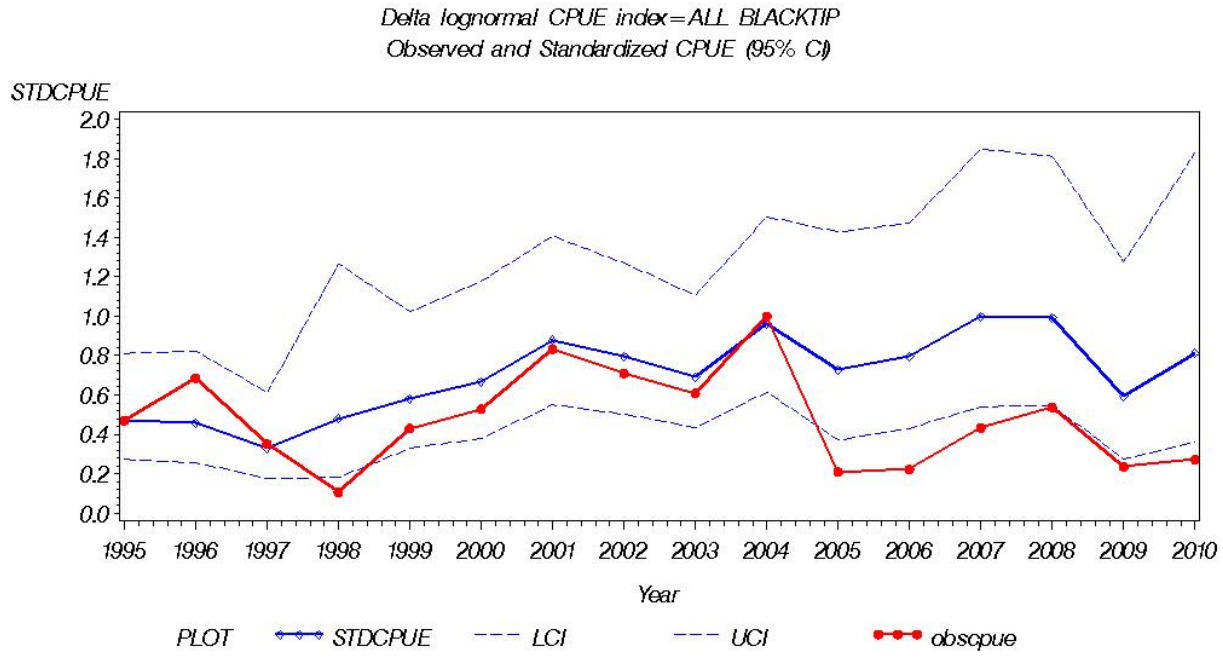
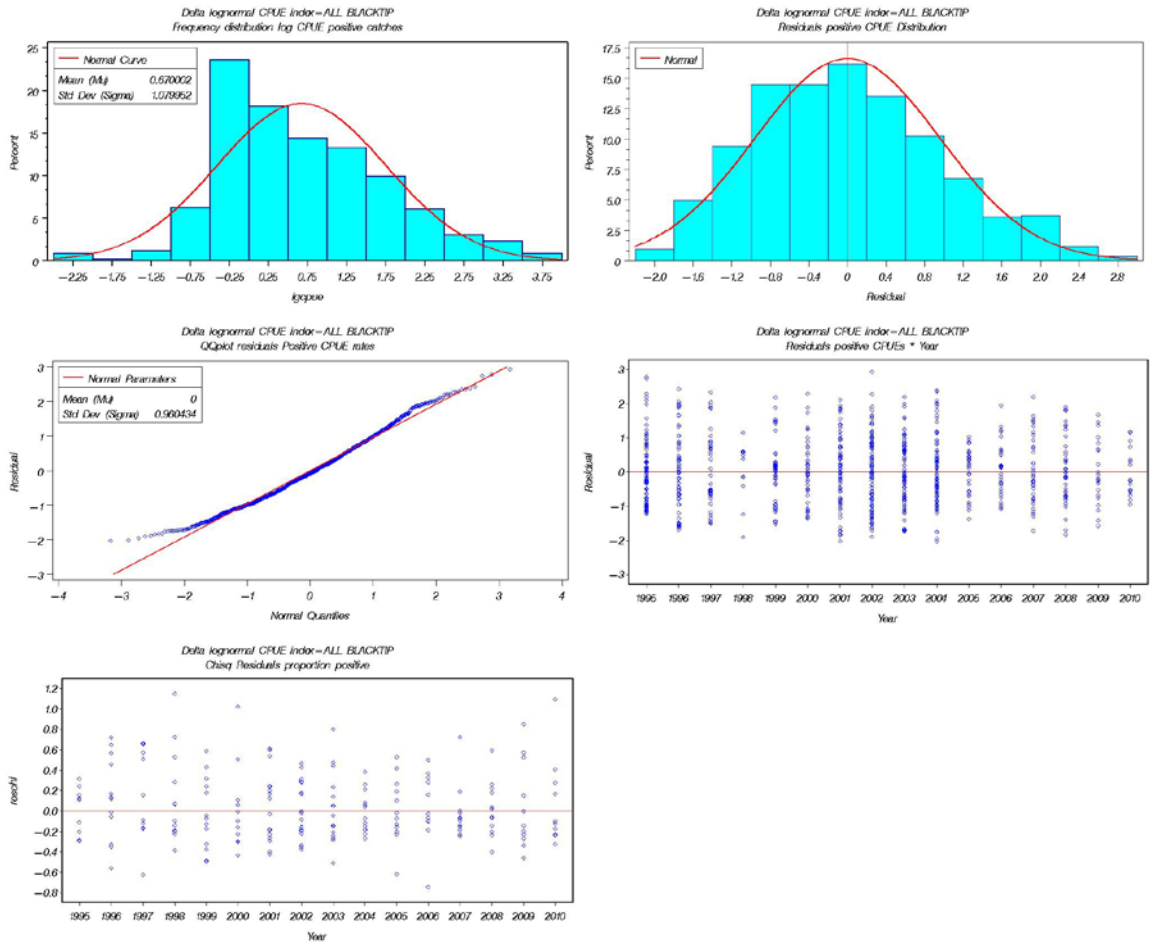


Table 3. Frequency of observations by factor and level used in the development of the standardized catch rate series.

FACTOR	SERIES	LEVEL	FREQUENCY OF TOTAL
Year	All	1995	10.5
		1996	7.8
		1997	5.7
		1998	2.9
		1999	4.2
		2000	4.8
		2001	7.2
		2002	9.7
		2003	9.7
		2004	8.3
		2005	6.3
		2006	6.1
		2007	6.0
		2008	5.4
		2009	3.4
		2010	2.1
	Panama City	1995	0
		1996	1.8
		1997	1.9
		1998	4.8
		1999	3.5
		2000	3.8
		2001	6.5
		2002	9.2
		2003	10.6
		2004	8.3
		2005	10.6
		2006	10.3
		2007	10.1
		2008	9.1
		2009	5.8
		2010	3.5
Year	Mote	1995	25.8
		1996	16.5
		1997	11.1
		1998	0.0
		1999	5.4
		2000	6.2
		2001	8.2
		2002	10.3
		2003	8.2
		2004	8.2
Area	All	Apalachicola Delta	15.2
		Charlotte Harbor	16.2
		Crooked Island Sound	19.5
		St. Andrew Bay	10.7
		St. Joe Bay	13.8
		Tampa Bay	6.5
		Yankeetown	18.1
	Panama City	Apalachicola Delta	25.7
		Crooked Island Sound	33.0
		St. Andrew Bay	18.1

		St. Joe Bay	23.3
	Mote	Charlotte Harbor	39.8
		Tampa Bay	15.9
		Yankeetown	44.3
Season	All	Fall	23.8
		Spring	25.9
		Summer	50.3
	Panama City	Fall	25.0
		Spring	26.4
		Summer	48.7
	Mote	Fall	22.2
		Spring	25.2
		Summer	52.7
Set Depth	All	>5.0 m	52.4
		<5.0 m	47.6
	Panama City	>5.0 m	21.3
		<5.0 m	78.7
	Mote	>5.0 m	97.5
		<5.0 m	2.5
Set Begin	All	Dawn	42.2
		Day	51.3
		Dusk	6.0
		Night	0.5
Set Begin	Panama City	Dawn	46.4
		Day	48.0
		Dusk	4.8
		Night	0.8
Set Begin	Mote	Dawn	36.2
		Day	56.2
		Dusk	7.6
		Night	0.0
Bottom Type	All	Mud	68.1
		Sand	24.7
		Sea grass	7.2
		Shell	0.1
Bottom Type	Panama City	Mud	48.4
		Sand	39.6
		Sea grass	11.8
		Shell	0.1
Bottom Type	Mote	Mud	96.6
		Sand	3.0
		Sea grass	0.4
		Shell	0.0

Figure 4. Diagnostic plots of the frequency distribution of residuals, quantile-quantile plots, and distribution of residuals by year.



All blacktip sharks Panama City

A time series of abundance was generated for all blacktip sharks for the Panama City data set only. The proportion of positive sets (at least one blacktip shark was caught) was 30.7%. The stepwise construction of the model is summarized in Table 4 and the index statistics can be found in Table 5. The standardized abundance index is shown in Figure 5 and for comparison the index estimated at SEDAR 11 is provided. The diagnostic plots assessing the fit of the models were deemed acceptable (Figure 6).

Table 4. 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 all blacktip sharks for the Panama City survey. Final models selected are in bold.

Proportion positive-Binomial error distribution					
FACTOR	**DEVIANCE/DF**	**%DIFF**	**DELTA%**	**CHISQUARE**	**PR>CHI**
NULL	1.600				
YEAR	1.572	1.738	1.74	38.980	0.0004
YEAR+					
AREA	1.138	28.828	27.09	262.100	<.0001
BOTTOMTYPE	1.348	15.724		137.630	<.0001
SEASON	1.532	4.214		26.750	<.0001
SETDEPTH	1.567	2.051		4.590	0.0322
SETBEGIN	1.575	1.557		3.030	0.3877
YEAR+AREA+					
SEASON	1.103	31.022	2.19	23.060	<.0001
BOTTOMTYPE	1.124	29.759		12.240	0.007
SETDEPTH	1.138	28.828		1.140	0.287
YEAR+AREA+SEASON+					
BOTTOMTYPE	1.0884	31.954	0.93	12.140	0.007
Mixed Model	**AIC**				
YEAR+AREA+SEASON	520.300				
YEAR+AREA+SEASON YEAR*AREA	520.300				
YEAR+AREA+SEASON YEAR*SEASON	**518.500**				

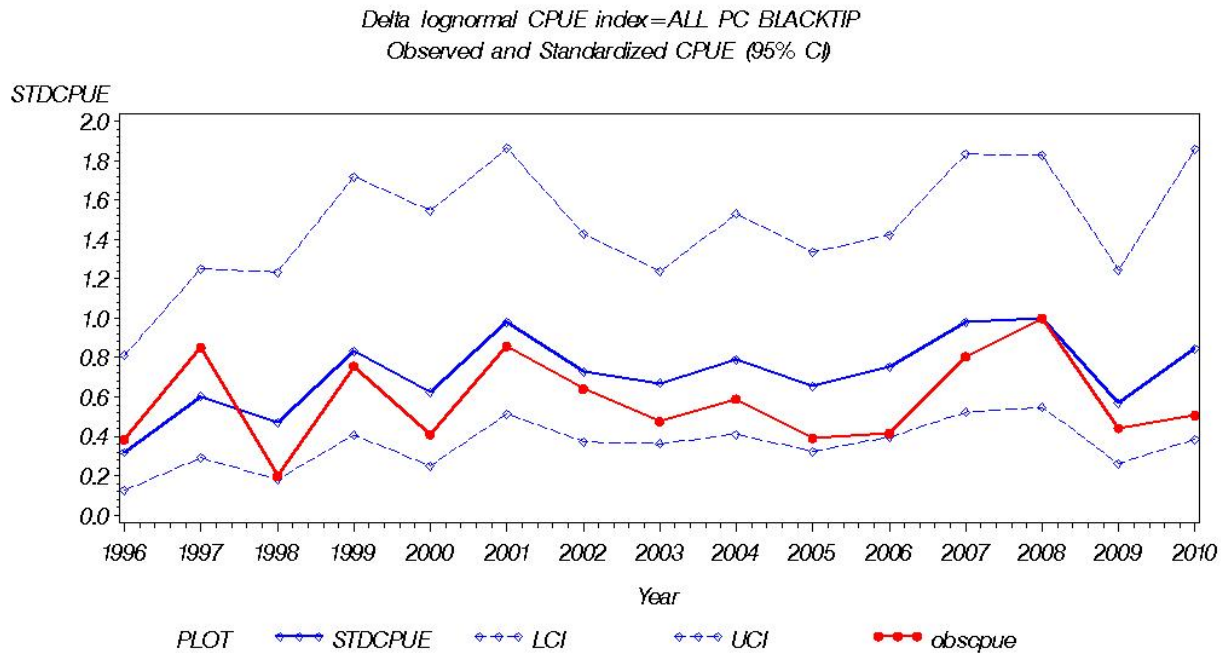
Proportion positive-Lognormal error distribution

FACTOR	**DEVIANCE/DF**	**%DIFF**	**DELTA%**	**CHISQUARE**	**PR>CHI**
NULL	0.921				
YEAR	0.867	5.800	5.80	40.170	0.0002
YEAR+					
AREA	0.769	16.487	10.69	55.420	<.0001
BOTTOMTYPE	0.833	9.558		19.740	<.0001
SETBEGIN	0.861	6.539		6.560	0.0874
SETDEPTH	0.863	6.321		3.460	0.0628
SEASON	0.865	6.039		3.200	0.2018
YEAR+AREA+					

SETBEGIN	0.766	16.759	0.27	4.500	0.212
BOTTOMTYPE	0.772	16.140		0.260	0.878
Mixed Model	**AIC**				
YEAR+AREA	1133.100				
YEAR+AREA YEAR*AREA	**1132.900**				

Table 5. The standardized and nominal index (number of sharks per net hour) of absolute abundance, and coefficients of variation (CV) for all blacktip sharks captured in the Panama City survey. N=number of sets.

YEAR	N	ABSOLUTE STANDARDIZED INDEX	CV	ABSOLUTE NOMINAL INDEX	CV
1996	26	0.339	0.49	0.507	0.33
1997	27	0.640	0.38	1.122	0.22
1998	68	0.501	0.51	0.261	0.98
1999	49	0.887	0.37	0.998	0.33
2000	54	0.662	0.48	0.541	0.59
2001	92	1.040	0.33	1.132	0.30
2002	130	0.775	0.35	0.845	0.32
2003	150	0.712	0.31	0.627	0.36
2004	117	0.842	0.34	0.778	0.37
2005	149	0.698	0.37	0.515	0.50
2006	145	0.798	0.33	0.547	0.48
2007	143	1.040	0.32	1.063	0.31
2008	128	1.063	0.31	1.320	0.25
2009	82	0.606	0.41	0.583	0.42
2010	50	0.899	0.41	0.668	0.55



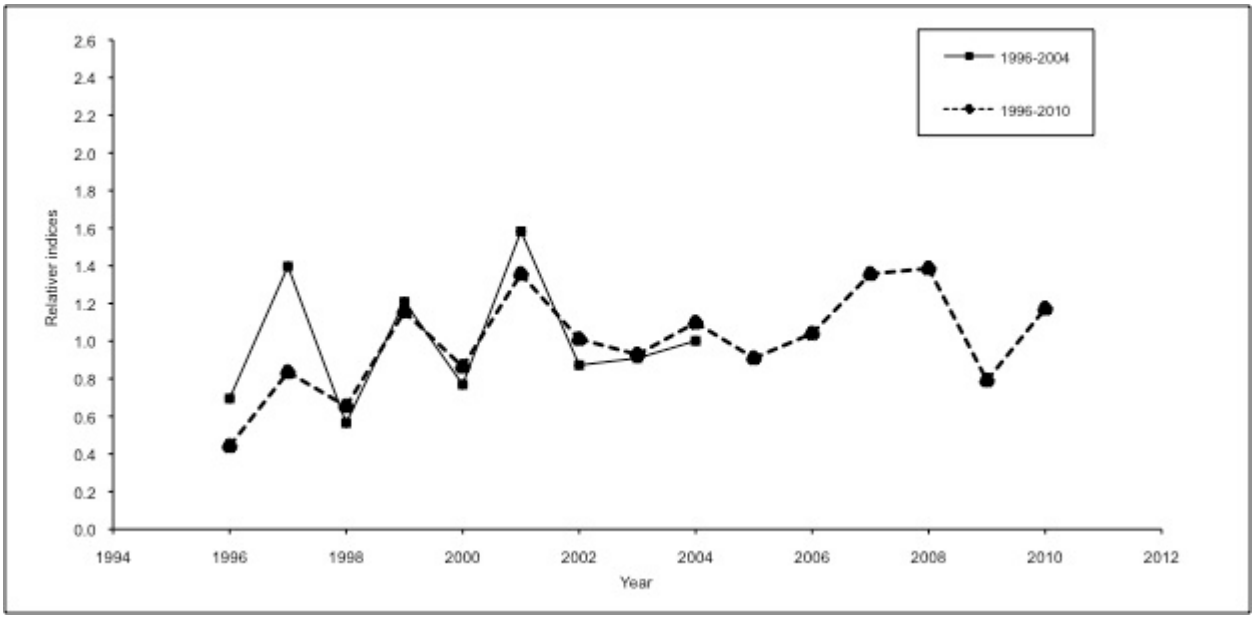


Figure 5. Nominal (obscpue) and standardized (STDCPUE) indices of abundance for all blacktip sharks from the Panama City survey. The dashed lines are the 95% confidence limits (LCL, UCL) for the standardized index. Each index has been divided by the maximum of the index. For comparison, the index determined at SEDAR11 is provided to demonstrate continuity.

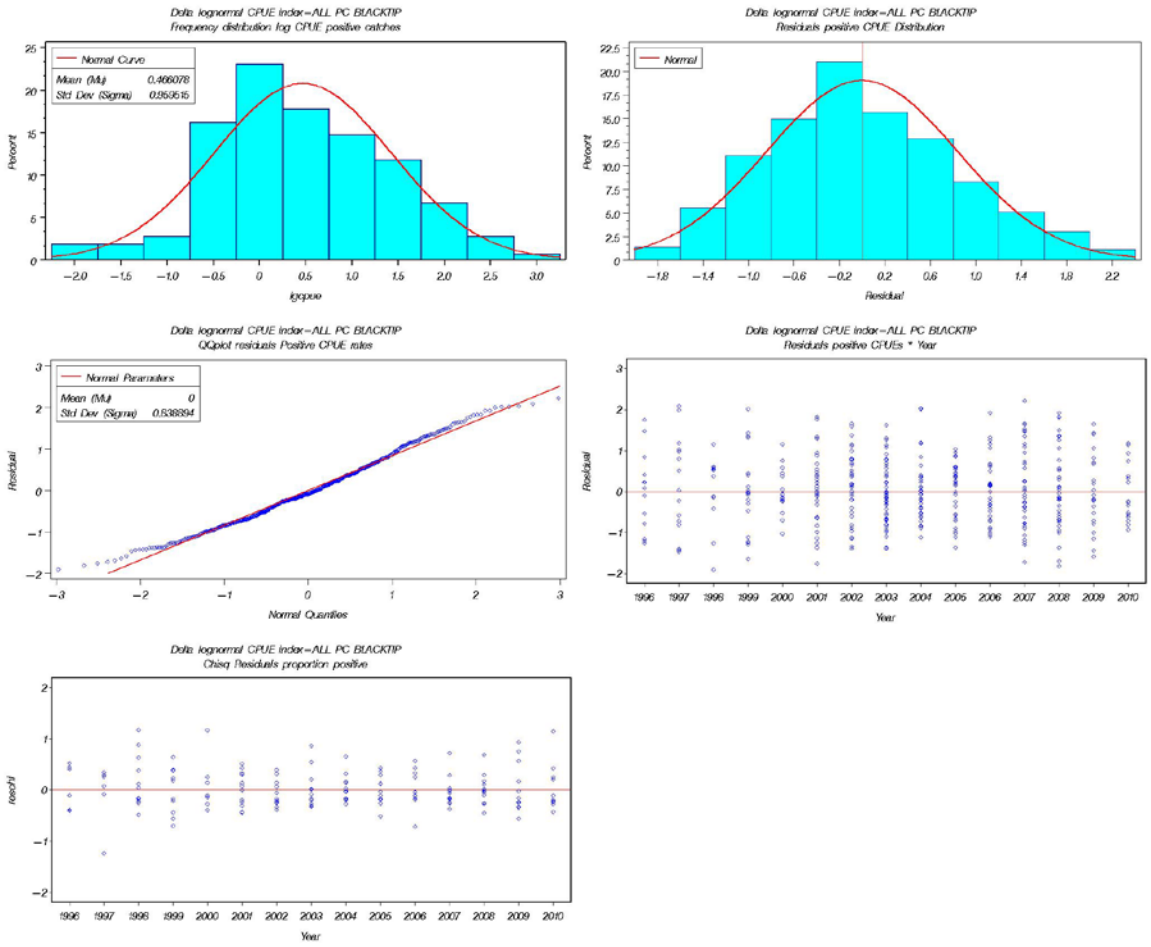


Figure 6. Diagnostic plots of the frequency distribution of residuals, quantile-quantile plots, and distribution of residuals by year.

All blacktip sharks Mote Marine Laboratory

A time series of abundance was generated for all blacktip sharks for the Mote Marine Laboratory data set only. As no adults were captured, this series would include Ages 0-maturity. The proportion of positive sets (at least one blacktip shark was caught) was 40.6%. The stepwise construction of the model is summarized in Table 6 and the index statistics can be found in Table 7. The standardized abundance index is shown in Figure 7 and the diagnostic plots assessing the fit of the models were deemed acceptable (Figure 8).

Table 6. 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 all blacktip sharks for the Mote Marine Laboratory survey. Final models selected are in bold.

Proportion positive-Binomial error distribution					
FACTOR	**DEVIANCE/DF**	**%DIFF**	**DELTA%**	**CHISQUARE**	**PR>CHI**
NULL	2.266				
YEAR	2.034	10.226	10.23	51.950	<.0001
YEAR+					
AREA	1.788	21.075	10.85	39.470	<.0001
SETBEGIN	2.004	11.568		8.440	0.0147
SEASON	2.007	11.400		7.910	0.0192
BOTTOMTYPE	2.045	9.759		2.540	0.2806
SETDEPTH	2.048	9.609		0.000	0.9442
YEAR+AREA+					
SEASON	1.7604	22.302	1.23	7.52	0.0233
SETBEGIN	1.7712	21.825		5.99	0.0501
Mixed Model	AIC				
YEAR+AREA+SEASON	**111.6**				
YEAR+AREA+SEASON YEAR*AREA	111.6				
YEAR+AREA+SEASON YEAR*SEASON	113.6				

Proportion positive-Lognormal error distribution					
FACTOR	**DEVIANCE/DF**	**%DIFF**	**DELTA%**	**CHISQUARE**	**PR>CHI**
NULL	1.343				
YEAR	1.294	3.700	3.70	22.940	0.0034
YEAR+					
AREA	1.247	7.161	3.46	16.470	0.0003
SEASON	1.283	4.474		5.250	0.0724
BOTTOMTYPE	1.295	3.588		1.610	0.4474
SETDEPTH	1.295	3.573		0.510	0.4759
SETBEGIN	1.300	3.223		0.130	0.9389
Mixed Model	AIC				
YEAR+AREA	1214.2				
YEAR+AREA YEAR*AREA	**1209.9**				

Table 7. The standardized and nominal index (number of sharks per net hour) of absolute abundance, and coefficients of variation (CV) for all blacktip shark captured in the Mote Marine Laboratory survey. N=number of sets.

YEAR	N	ABSOLUTE STANDARDIZED INDEX	CV	ABSOLUTE NOMINAL INDEX	CV
1995	250	1.436	0.21	1.154	0.26
1996	160	2.152	0.29	1.877	0.34
1997	108	0.787	0.43	0.798	0.42
1998					
1999	52	1.169	0.40	1.111	0.42
2000	60	1.833	0.35	1.979	0.33
2001	80	2.391	0.28	3.094	0.21
2002	100	2.495	0.26	2.914	0.22
2003	80	2.306	0.33	3.118	0.24
2004	80	3.431	0.25	4.907	0.18

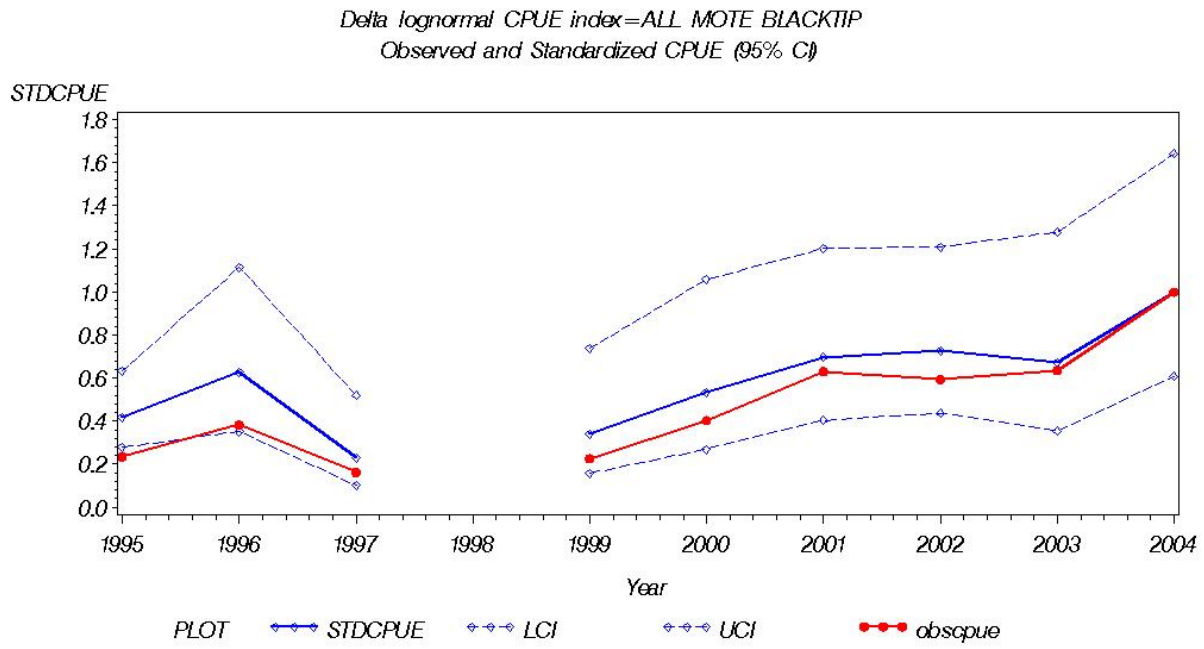


Figure 7. Nominal (obscpue) and standardized (STDCPUE) indices of abundance for all blacktip sharks from the Mote Marine Laboratory survey. The dashed lines are the 95% confidence limits (LCL, UCL) for the standardized index. Each index has been divided by the maximum of the index.

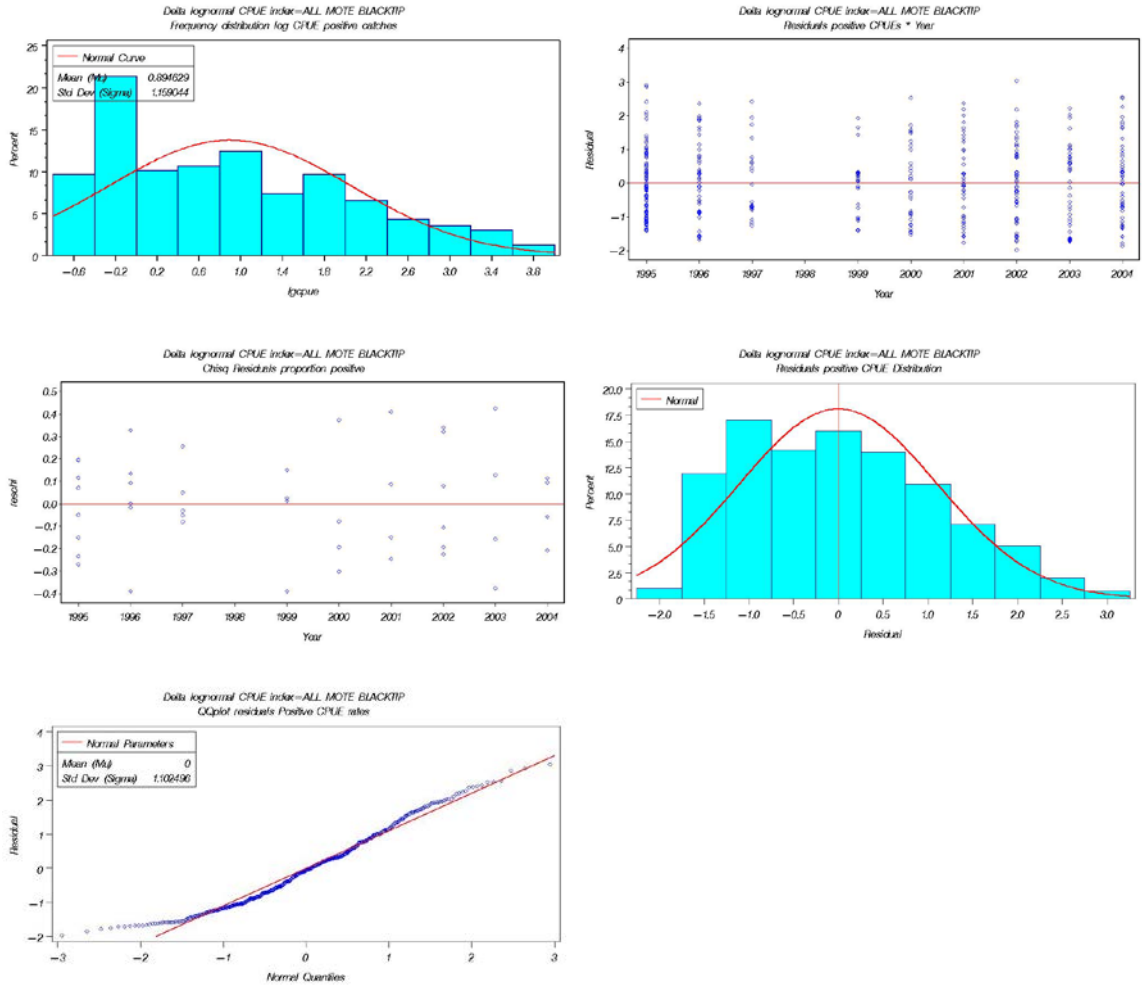


Figure 8. Diagnostic plots of the frequency distribution of residuals, quantile-quantile plots, and distribution of residuals by year for the Mote Marine Laboratory Survey.

Juvenile blacktip sharks combined

A time series of abundance was determined for juvenile blacktip sharks for data from combined surveys. Juvenile sharks were regarded as all those sharks captured from age 1 until maturity. The proportion of positive sets (at least one blacktip shark was caught) was 22.3%. The stepwise construction of the model is summarized in Table 8 and the index statistics can be found in Table 9. The standardized abundance index is shown in Figure 9 and the 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 and mixed model formulations of the proportion of positive and positive catches for juvenile blacktip sharks for both surveys. Final models selected are in bold.

Proportion positive-Binomial error distribution					
FACTOR	DEVIANCE/DF	%DIFF	DELTA%	CHISQUARE	PR>CHI
NULL	1.4705				
YEAR	1.4534	1.163	1.163	34.85	0.0026
YEAR+					
AREA	1.1528	21.605	20.442	232.72	<.0001
BOTTOMTYPE	1.3623	7.358		72.51	<.0001
SEASON	1.4253	3.074		24.02	<.0001
SURVEY	1.4292	2.809		19.65	<.0001
SETBEGIN	1.455	1.088		3.54	0.316
SETDEPTH	1.4545	1.088		0.66	0.4178
YEAR+AREA+					
SEASON	1.121	23.740	2.135	25.65	<.0001
BOTTOMTYPE	1.136	22.761		16.08	0.001
SURVEY	1.153	21.605		0.00	.
YEAR+AREA+SEASON					
BOTTOMTYPE	1.103	24.991	1.251	16.98	0.001
Mixed Model	**AIC**				
YEAR+AREA+SEASON	678.1				
YEAR+AREA+SEASON YEAR*AREA	**678.0**				
YEAR+AREA+SEASON YEAR*SEASON	676.3				

Proportion positive-Lognormal error distribution					
FACTOR	**DEVIANCE/DF**	**%DIFF**	**DELTA%**	**CHISQUARE**	**PR>CHI**
NULL	0.7642				
YEAR	0.7073	7.446	7.446	56.28	<.0001
YEAR+					
AREA	0.6586	13.818	6.373	43.96	<.0001
SURVEY	0.7021	8.126		4.89	0.027
BOTTOMTYPE	0.705	7.747		3.76	0.1528

SETDEPTH	0.7075	7.420		0.83	0.3627
SETBEGIN	0.7085	7.289		2.19	0.5343
SEASON	0.7098	7.119		0.18	0.9158
YEAR+AREA+					
SURVEY	0.6586	13.818		0	
Mixed Model	**AIC**				
YEAR+AREA	**1306.5**				
YEAR+AREA YEAR*AREA	1308.1				

Table 9. The standardized and nominal index (number of sharks per net hour) of absolute abundance, and coefficients of variation (CV) for all juvenile blacktip sharks from both surveys. N=number of sets.

YEAR	N	ABSOLUTE STANDARDIZED INDEX	CV	ABSOLUTE NOMINAL INDEX	CV
1995	250	0.269	0.33	0.156	0.57
1996	186	0.219	0.35	0.241	0.32
1997	135	0.247	0.36	0.237	0.38
1998	68	0.333	0.49	0.228	0.72
1999	101	0.406	0.34	0.414	0.33
2000	114	0.356	0.36	0.291	0.44
2001	172	0.547	0.27	0.524	0.28
2002	230	0.477	0.25	0.465	0.26
2003	230	0.397	0.26	0.354	0.30
2004	197	0.745	0.22	0.709	0.24
2005	149	0.477	0.32	0.434	0.36
2006	145	0.460	0.33	0.388	0.40
2007	143	0.670	0.32	0.852	0.25
2008	128	0.579	0.30	0.851	0.20
2009	82	0.268	0.46	0.278	0.45
2010	50	0.456	0.51	0.417	0.55

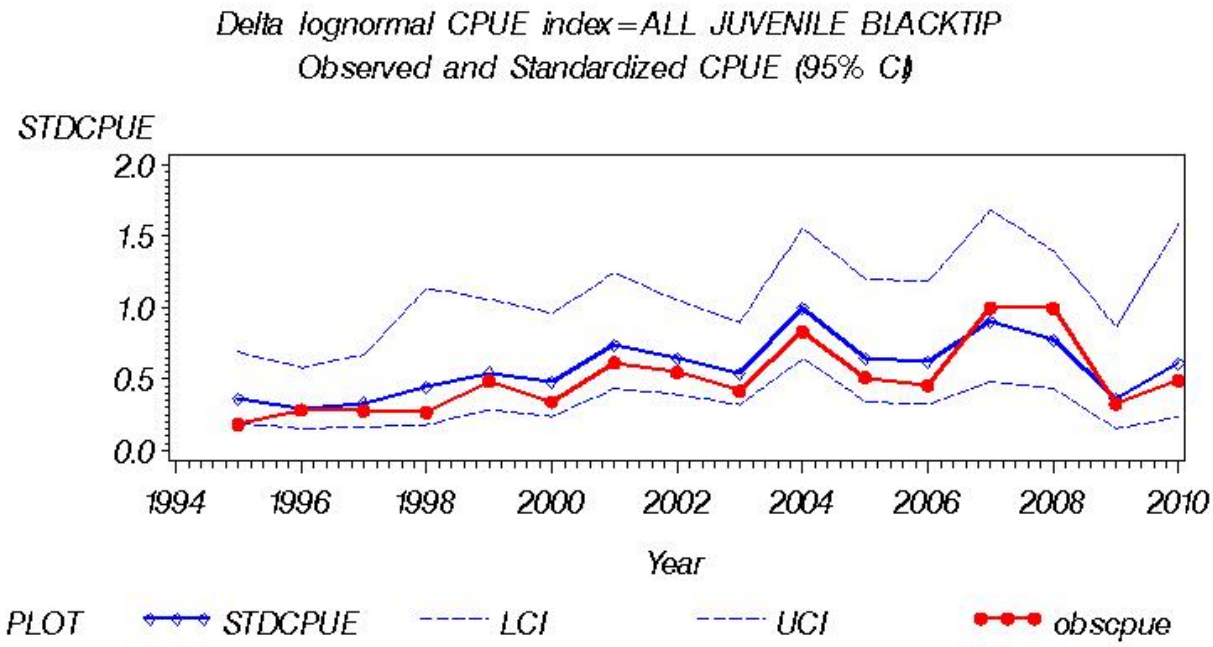


Figure 9. Nominal (obscpue) and standardized (STDCPUE) indices of abundance for juvenile blacktip sharks for both surveys. The dashed lines are the 95% confidence limits (LCL, UCL) for the standardized index. Each index has been divided by the maximum of the index

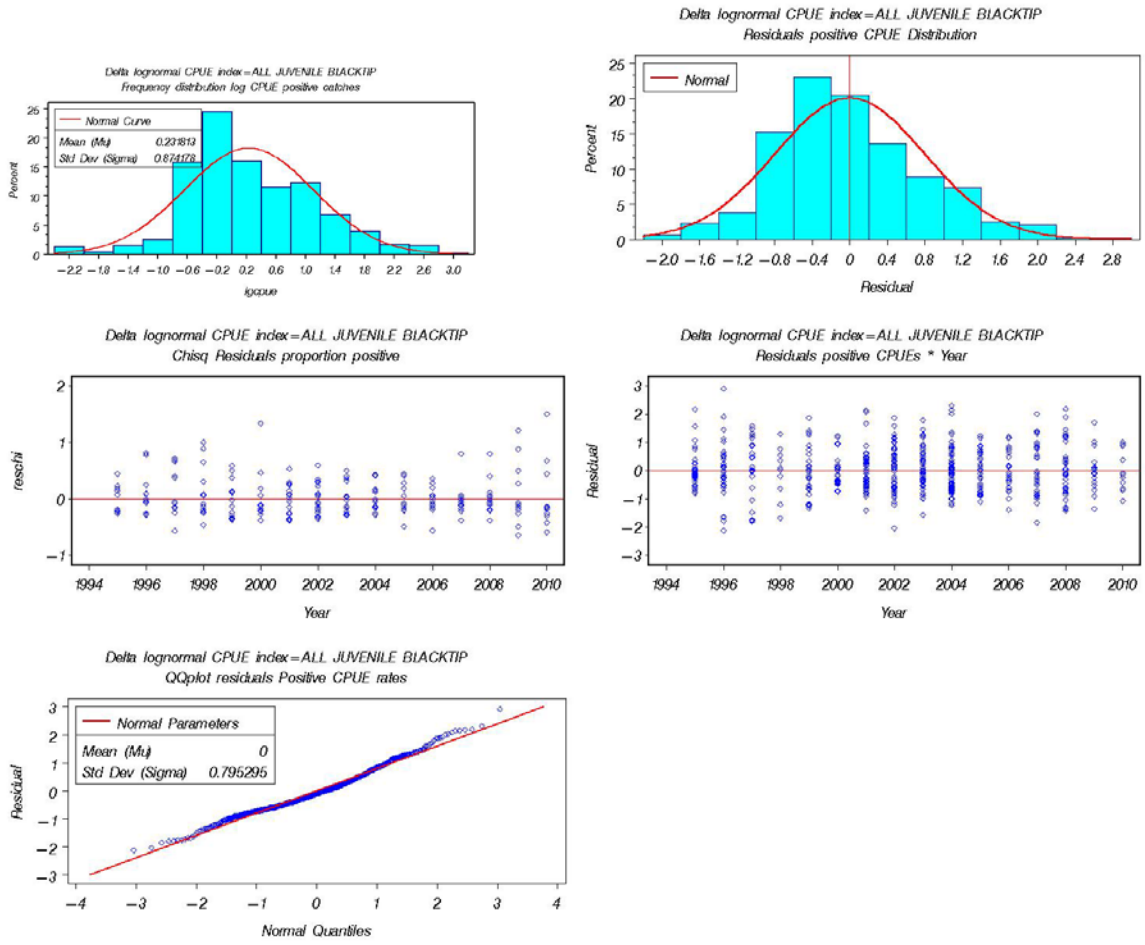


Figure 10. Diagnostic plots of the frequency distribution of residuals, quantile-quantile plots, and distribution of residuals by year from both surveys.

Juvenile blacktip sharks Panama City

A time series of abundance was determined for juvenile blacktip sharks for data from the Panama City survey. Juvenile sharks were regarded as all those sharks captured from age 1 until maturity. The proportion of positive sets (at least one blacktip shark was caught) was 25.8%. The stepwise construction of the model is summarized in Table 10 and the index statistics can be found in Table 11. The standardized abundance index is shown in Figure 11 and the diagnostic plots assessing the fit of the models were deemed acceptable (Figure 12).

Table 10. 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 juvenile blacktip sharks for the Panama City survey. Final models selected are in bold.

Proportion positive-Binomial error distribution					
FACTOR	**DEVIANCE/DF**	**%DIFF**	**DELTA%**	**CHISQUARE**	**PR>CHI**
NULL	1.3976				
YEAR	1.3655	2.297	2.30	38.75	0.0004
YEAR+					
AREA	1.0523	24.707	22.41	190.14	<.0001
BOTTOMTYPE	1.2005	14.103		102.11	<.0001
SEASON	1.3219	5.416		28.67	<.0001
SETDEPTH	1.3551	3.041		7.55	0.006
SETBEGIN	1.3707	1.925		1	0.8015
YEAR+AREA+					
SEASON	1.0142	27.433	2.73	24.68	<.0001
BOTTOMTYPE	1.037	25.801		12.2	0.0067
SETDEPTH	1.0476	25.043		3.82	0.0505
YEAR+AREA+SEASON+					
BOTTOMTYPE	0.9987	28.542	1.11	12.14	0.0069
MIXED MODEL	**AIC**				
YEAR+AREA+SEASON	542.4				
YEAR+AREA+SEASON YEAR*AREA	542.4				
YEAR+AREA+SEASON YEAR*SEASON	**541.0**				

Proportion positive-Lognormal error distribution					
FACTOR	**DEVIANCE/DF**	**%DIFF**	**DELTA%**	**CHISQUARE**	**PR>CHI**
NULL	0.8685				
YEAR	0.8015	7.714	7.71	43.61	<.0001
YEAR+					
AREA	0.7409	14.692	6.98	31.85	<.0001
BOTTOMTYPE	0.7863	9.465		9.1	0.0105
SETBEGIN	0.7988	8.025		4.39	0.222
SETDEPTH	0.8023	7.622		0.72	0.3976
SEASON	0.8055	7.254		0.27	0.8719

YEAR+AREA+					
BOTTOMTYPE	0.7428	14.473	-0.22	1.21	0.5469
MIXED MODEL	**AIC**				
YEAR+AREA	**939.4**				
YEAR+AREA YEAR*AREA	941.4				

Table 11. The standardized and nominal index (number of sharks per net hour) of absolute abundance, and coefficients of variation (CV) for juvenile blacktip sharks (Age 1-maturity) from the Panama City survey. N=number of sets.

YEAR	N	ABSOLUTE STANDARDIZED INDEX	CV	ABSOLUTE NOMINAL INDEX	CV
1996	26	0.306	0.52	0.456	0.35
1997	27	0.594	0.38	0.925	0.25
1998	68	0.431	0.55	0.228	1.04
1999	49	0.714	0.39	0.709	0.39
2000	54	0.504	0.57	0.395	0.72
2001	92	0.693	0.37	0.739	0.35
2002	130	0.574	0.34	0.606	0.32
2003	150	0.574	0.32	0.452	0.40
2004	117	0.731	0.31	0.676	0.34
2005	149	0.635	0.34	0.434	0.50
2006	145	0.607	0.35	0.388	0.55
2007	143	0.886	0.33	0.852	0.34
2008	128	0.753	0.31	0.851	0.27
2009	82	0.360	0.52	0.278	0.68
2010	50	0.603	0.54	0.417	0.78

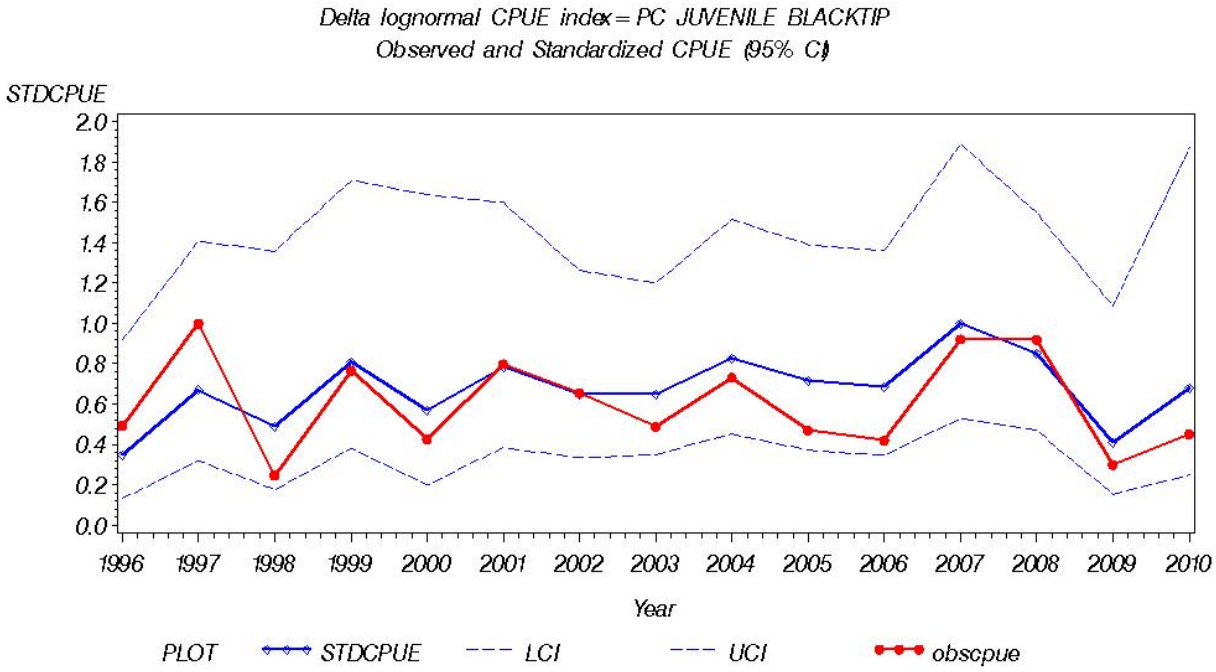


Figure 11. Nominal (obscpue) and standardized (STDCPUE) indices of abundance for juvenile blacktip sharks from the Panama City survey. The dashed lines are the 95% confidence limits (LCL, UCL) for the standardized index. Each index has been divided by the maximum of the index

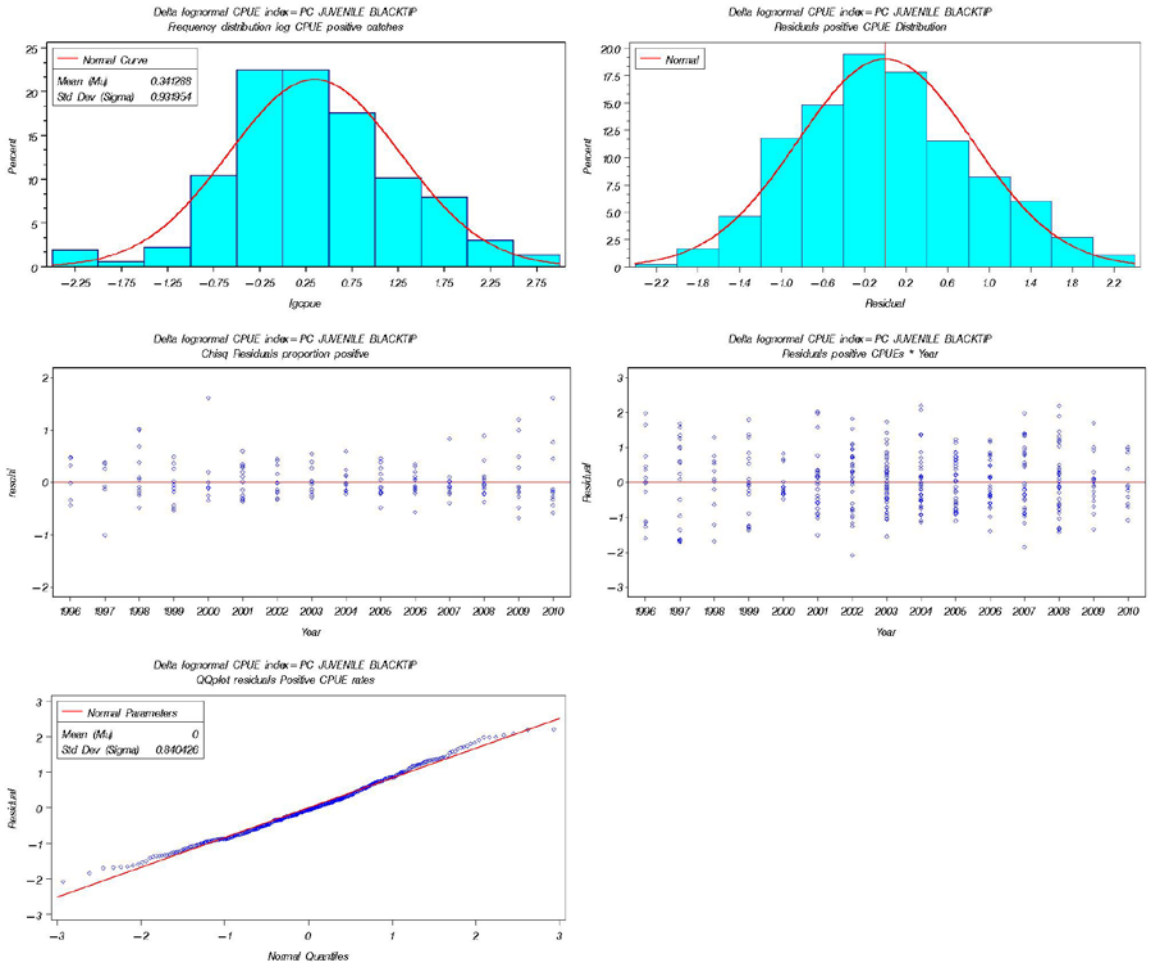


Figure 12. Diagnostic plots of the frequency distribution of residuals, quantile-quantile plots, and distribution of residuals by year from both surveys.

Juvenile blacktip sharks Mote Marine Laboratory

A time series of abundance was determined for juvenile blacktip sharks for data from the Mote Marine Laboratory survey. Juvenile sharks were regarded as all those sharks captured from age 1 until maturity. The proportion of positive sets (at least one blacktip shark was caught) was 17.0%. The stepwise construction of the model is summarized in Table 12 and the index statistics can be found in Table 13. The standardized abundance index is shown in Figure 13 and the diagnostic plots assessing the fit of the models were deemed acceptable (Figure 14).

Table 12. 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 juvenile blacktip sharks for the Mote Marine Laboratory survey. Final models selected are in bold.

Proportion positive-Binomial error distribution					
FACTOR	**DEVIANCE/DF**	**%DIFF**	**DELTA%**	**CHISQUARE**	**PR>CHI**
NULL	1.6704				
YEAR	1.4916	10.704	10.70	37.49	<.0001
YEAR+					
SETBEGIN	1.461	12.536	1.83	7.06	0.0294
AREA	1.4703	11.979		5.82	0.0545
SEASON	1.4898	10.812		3.22	0.1996
SETDEPTH	1.5027	10.040		0.01	0.9044
MIXED MODEL	**AIC**				
YEAR+SETBEGIN	**44.2**				
YEAR+SETBEGIN YEAR*SETBEGIN	44.9				
Proportion positive-Lognormal error distribution					
FACTOR	**DEVIANCE/DF**	**%DIFF**	**DELTA%**	**CHISQUARE**	**PR>CHI**
NULL	0.4516				
YEAR	0.4296	4.872	4.87	16.46	0.0362
YEAR+					
AREA	0.428	5.226	0.35	2.75	0.2524
SEASON	0.4283	5.159		2.63	0.2682
SETDEPTH	0.43	4.783		0.93	0.3358
SETBEGIN	0.4315	4.451		1.42	0.4919
MIXED MODEL	**AIC**				
YEAR	**337.9**				

Table 13. The standardized and nominal index (number of sharks per net hour) of absolute abundance, and coefficients of variation (CV) for juvenile blacktip sharks (Age 1-maturity) from the Mote Marine Laboratory survey. N=number of sets.

YEAR	N	ABSOLUTE STANDARDIZED INDEX	CV	ABSOLUTE NOMINAL INDEX	CV
1995	250	0.149	0.26	0.156	0.25
1996	160	0.166	0.33	0.206	0.27
1997	108	0.066	0.72	0.065	0.74
1998					
1999	52	0.130	0.59	0.136	0.56
2000	60	0.199	0.39	0.198	0.39
2001	80	0.309	0.29	0.277	0.32
2002	100	0.271	0.29	0.281	0.28
2003	80	0.167	0.41	0.171	0.40
2004	80	0.650	0.21	0.756	0.18

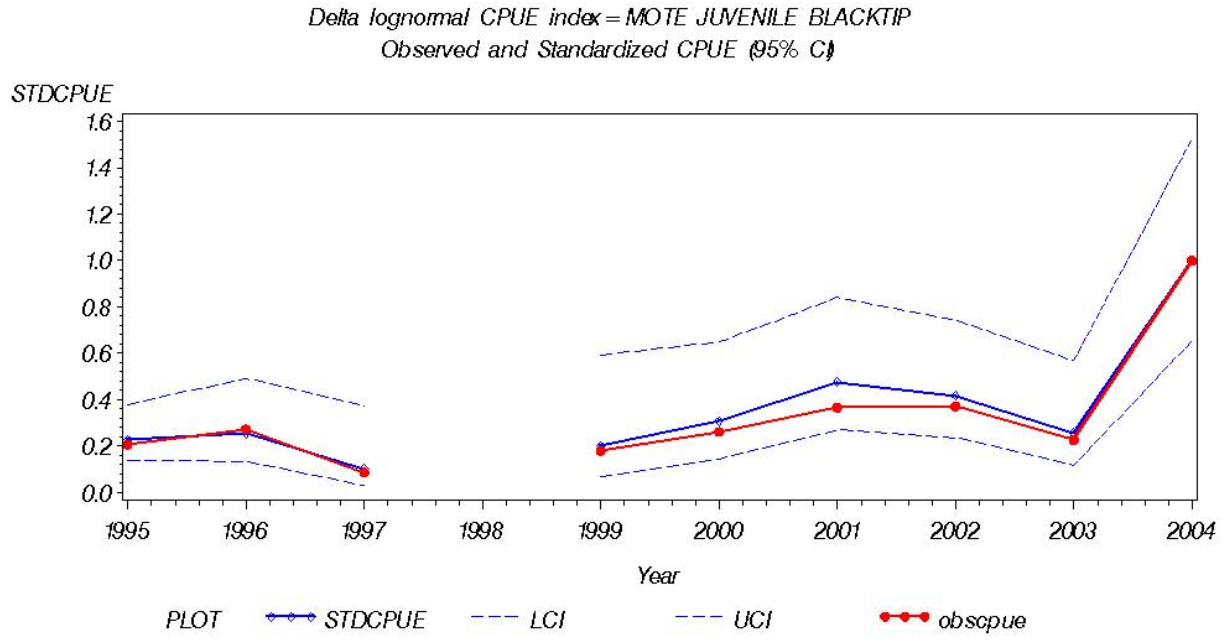


Figure 13. Nominal (obscpue) and standardized (STDCPUE) indices of abundance for juvenile blacktip sharks from the Mote Marine Laboratory survey. The dashed lines are the 95% confidence limits (LCL, UCL) for the standardized index. Each index has been divided by the maximum of the index

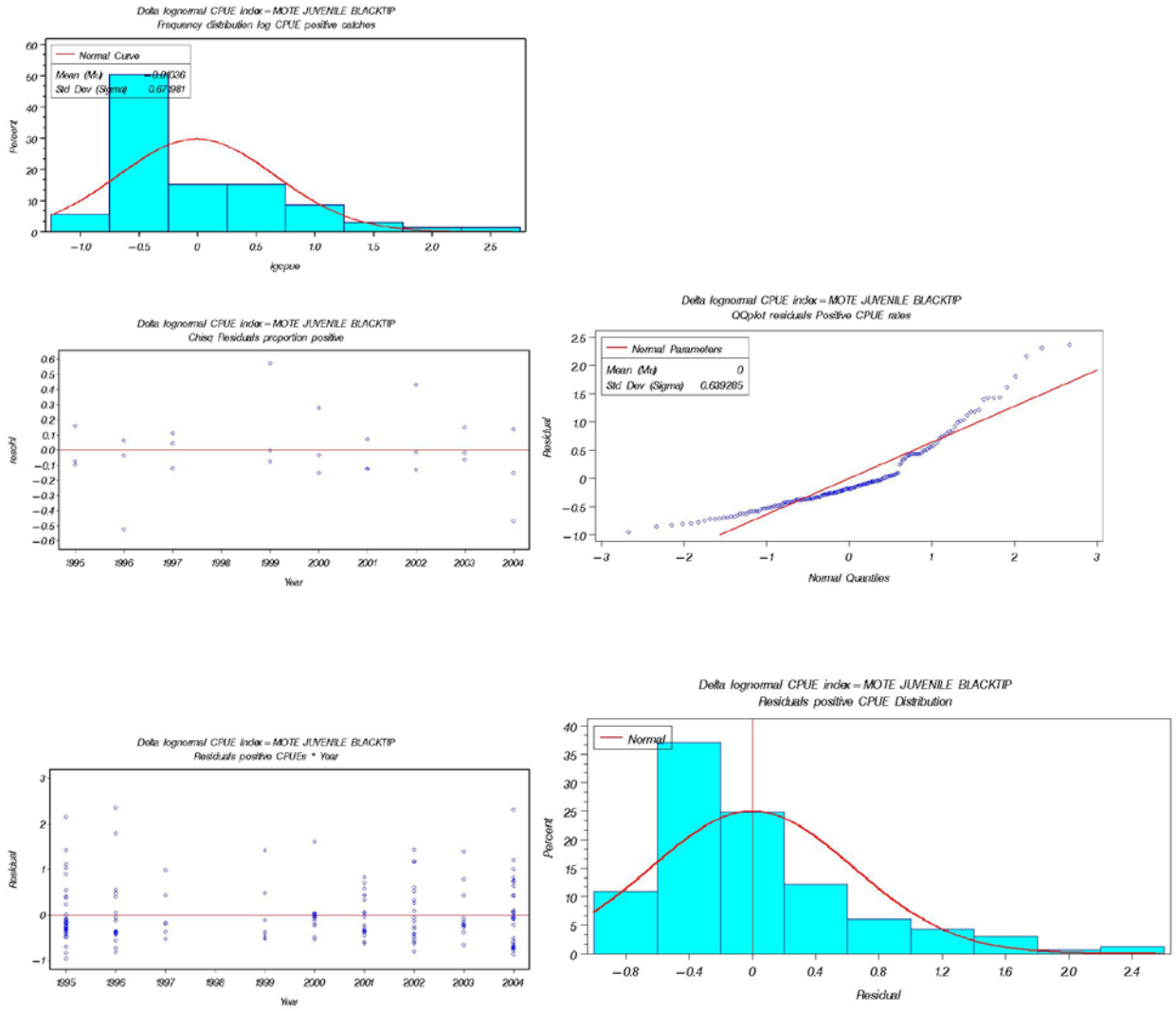


Figure 14. Diagnostic plots of the frequency distribution of residuals, quantile-quantile plots, and distribution of residuals by year from the Mote Marine Laboratory survey.

Age 0 blacktip sharks combined

A time series of abundance was determined for Age 0 blacktip sharks for data from the combined data sets. Age 0 sharks were regarded as all those sharks captured from birth to age 1. The proportion of positive sets (at least one blacktip shark was caught) was 20.4%. The stepwise construction of the model is summarized in Table 14 and the index statistics can be found in Table 15. The standardized abundance index is shown in Figure 15 and the diagnostic plots assessing the fit of the models were deemed acceptable (Figure 16).

Table 14. 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 Age 0 blacktip sharks. Final models selected are in bold.

Proportion positive-Binomial error distribution					
FACTOR	**DEVIANCE/DF**	**%DIFF**	**DELTA%**	**CHISQUARE**	**PR>CHI**
NULL	1.793				
YEAR	1.581	11.824	11.82	146.08	<.0001
YEAR+					
AREA	0.9173	48.840	37.02	378.48	<.0001
SURVEY	1.3354	25.521		139.34	<.0001
SETBEGIN	1.4495	19.158		75.32	<.0001
SEASON	1.5163	15.432		39.39	<.0001
SETDEPTH	1.5625	12.856		15.06	0.0018
YEAR+AREA+					
SEASON	0.8857	50.602	1.76	19.36	<.0001
SETBEGIN	0.9	49.219		Negative of Hessian not positive definite.	
MIXED MODEL	**AIC**				
YEAR+AREA+SEASON	**595.7**				
YEAR+AREA+SEASON YEAR*AREA	847.2				
YEAR+AREA+SEASON YEAR*SEASON	851.4				

Proportion positive-Lognormal error distribution					
FACTOR	**DEVIANCE/DF**	**%DIFF**	**DELTA%**	**CHISQUARE**	**PR>CHI**
NULL	1.407				
YEAR	1.3279	5.622	5.62	43.33	0.0001
YEAR+					
AREA	1.1207	20.348	14.73	87.47	<.0001
SURVEY	1.17	16.844		62.44	<.0001
SETDEPTH	1.2358	12.168		35.89	<.0001
SEASON	1.3241	5.892		3.43	0.1801
SETBEGIN	1.3322	5.316		0.49	0.7811
YEAR+AREA+					
SETDEPTH	1.1228	20.199	-0.15	0.11	0.7362
MIXED MODEL	**AIC**				
YEAR+AREA	**1435.9**				
YEAR+AREA YEAR*AREA	1424.9				

Table 15. The standardized and nominal index (number of sharks per net hour) of absolute abundance, and coefficients of variation (CV) for Age 0 blacktip sharks. N=number of sets.

YEAR	N	ABSOLUTE STANDARDIZED INDEX	CV	ABSOLUTE NOMINAL INDEX	CV
1995	250	0.665	0.20	0.998	0.13
1996	186	0.876	0.26	1.440	0.16
1997	135	0.361	0.34	0.604	0.20
1998	68	0.333	0.89	0.018	16.56
1999	101	0.745	0.30	0.605	0.37
2000	114	0.854	0.30	0.969	0.27
2001	172	1.324	0.24	1.472	0.21
2002	230	1.264	0.20	1.258	0.20
2003	230	1.171	0.24	1.118	0.25
2004	197	0.993	0.25	1.705	0.14
2005	149	0.697	0.95	0.053	12.41
2006	145	0.928	0.72	0.100	6.69
2007	143	1.754	0.33	0.179	3.27
2008	128	2.959	0.32	0.460	2.04
2009	82	1.907	0.54	0.286	3.62
2010	50	1.871	0.42	0.216	3.63

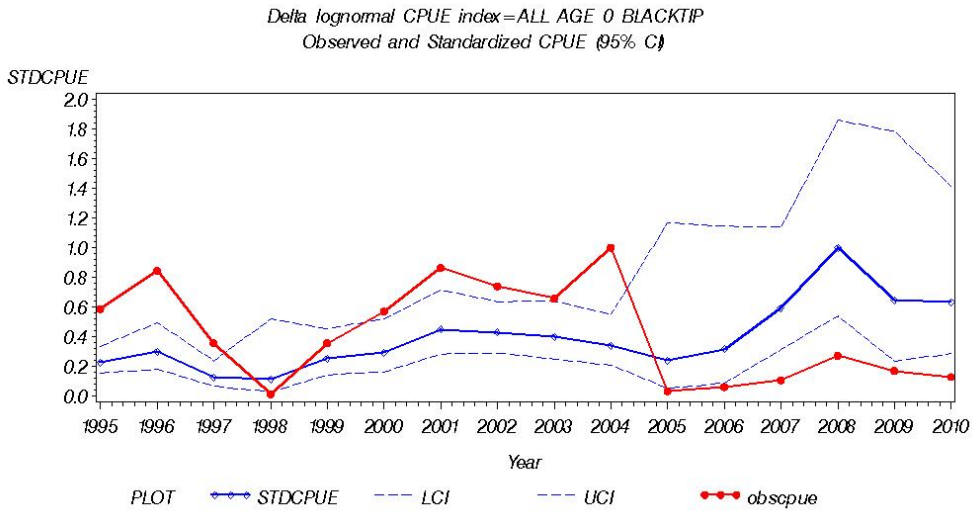


Figure 15. Nominal (obscpue) and standardized (STDCPUE) indices of abundance for Age 0 blacktip sharks. The dashed lines are the 95% confidence limits (LCL, UCL) for the standardized index. Each index has been divided by the maximum of the index

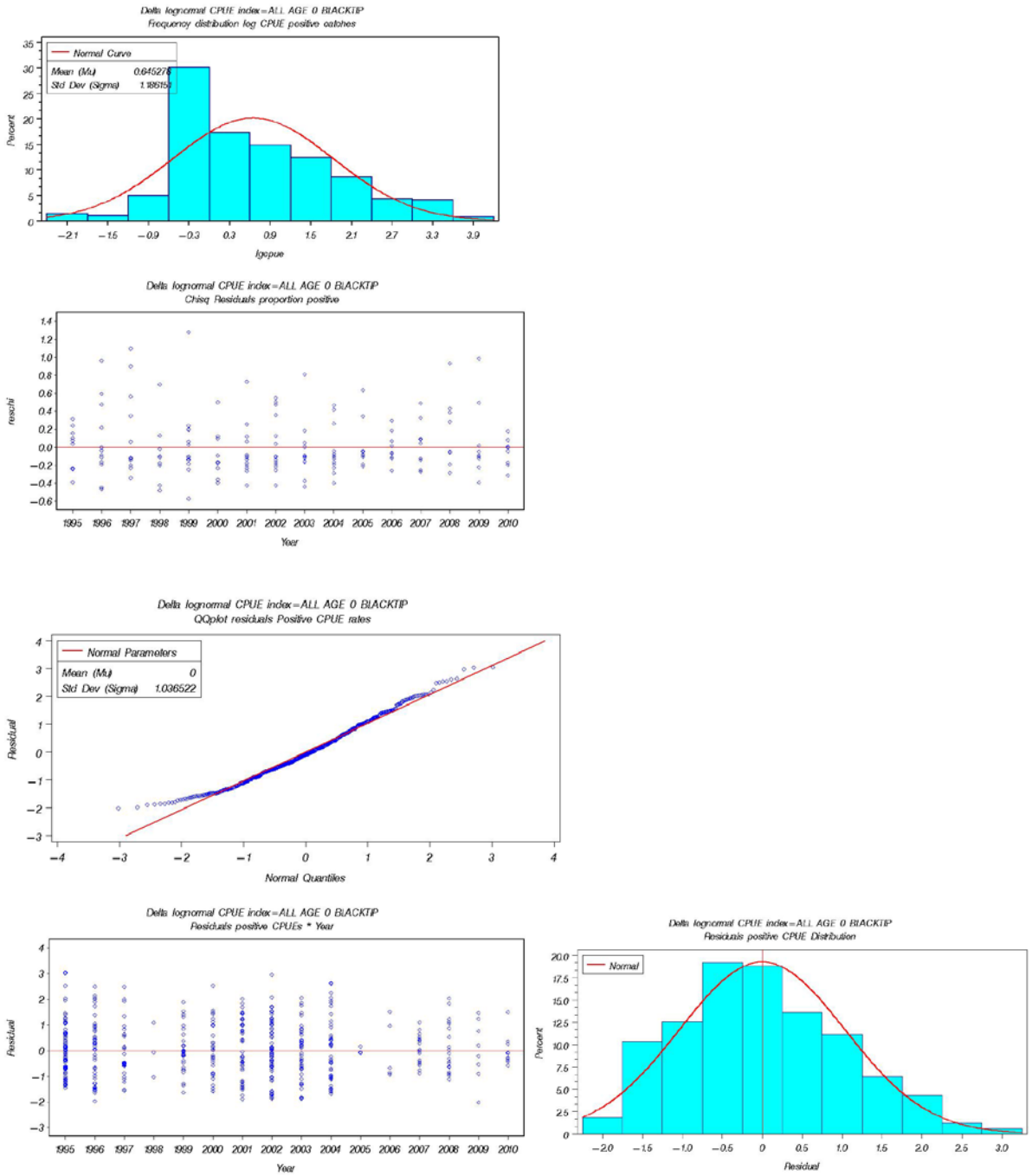


Figure 16. Diagnostic plots of the frequency distribution of residuals, quantile-quantile plots, and distribution of residuals by year for Age 0 blacktips.

REFERENCES

Lo, N.C., Jacobson, L. D., & Squire, J. L. (1992) Indices of relative abundance from fish spotter data based on delta lognormal models. Canadian Journal of Fisheries and Aquatic Sciences 49, 2515–2516.

McCullagh, P. & Nelder, J.A. (1989) Generalized Linear Models. Chapman & Hall, London.

Ortiz, M. & Arocha, F. (2004) Alternative error distribution models for standardization of catch rates of non-target species from a pelagic longline fishery: billfish species in theVenezuelan tuna longline fishery. Fisheries Research 70, 275–294.

Stefansson, G. (1996) Analysis of groundfish survey abundance data: combining the GLM and delta approaches. ICES Journal of Marine Science 53, 577–588.