Relative abundance of blacktip shark based on a fishery-independent gillnet survey off Texas

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INTRODUCTION

This paper determines a relative abundance index for blacktip sharks utilizing a fishery independent gillnet survey by the Texas Parks and Wildlife Department, Coastal Fisheries Division. The protocol for the survey, as it is constituted today, has been standardized since 1982 with the purpose of monitoring relative abundance and size of organisms, their spatial and temporal distribution, and species composition of the community and selected environmental parameters known to influence their distribution and abundance (Martinez-Andrade et al. 2010).

MATERIAL AND METHODS

Field Data Collection

Surveys were conducted in 10 major bay systems along the Texas coast in the north- western Gulf of Mexico from 1982 to 2010 (Figure 1). Barrier islands separate these bays from the Gulf of Mexico along the majority of the coastline, and saltwater exchange occurs via 6 major tidal inlets. Texas bays are shallow subtropical estuaries that are physically dynamic, and most are located near large human population centers. Coastal fisheries resource monitoring data were collected as a stratified cluster sampling design; each bay system serves as non-overlapping strata with a fixed number of samples. Gill-nets were deployed each spring (April, May, June) and fall (September, October, November; Martinez-Andrade et al. 2010). Sample locations were drawn independently and without replacement for each season (Martinez- Andrade et al. 2010). Sharks were sampled using standardized 183 m gill-nets perpendicular to shore. Nets were constructed of 4 panels with stretched mesh sizes of 76, 102, 127, and 152 mm. Gill-nets were deployed 1 h before sunset, fished overnight, and retrieved within 4 h of sunrise the following day, and a total set time was calculated for each sample. Each captured shark was identified to species, measured, and released. Abundance data were converted to catch per unit effort (CPUE) by dividing the number of sharks captured by 'soak time', in hours, of each net in the sample.

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" (28 levels): 1982-2010

"Area" (10 levels): locations of gillnet set with a major bay system (Figure 1).

"Season" (3 levels):
Spring=Apr-Jul
Other=Outside these periods
Fall=Sep-Nov

"Temperature" (3 levels)
<19.9° C
20.0-29.9° C

>30.0° C

“Salinity” (4 levels)
Fresh=0-5 ppt
Estuarine=6-30 ppt
Marine=30-39 ppt
Hypersaline=>40 ppt

“Dissolved oxygen” (3 levels)
Hypoxic=0-4.9 mg l^{-1}
Normoxic=5.0-10.0 mg l^{-1}
Hyperoxic=>10.0 mg l^{-1}

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

All blacktips

A total of 22137 gillnet sets were made since 1982. The majority of individuals captured were juveniles and the length distribution did not change significantly over the survey period (Figure 2). The proportion positive (i.e. number of sets that caught a blacktip shark) over the survey period was 3.6%.

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 are shown in 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 blacktip sharks. Final models selected are in bold.

Proportion positive-Binomial error distribution						
FACTOR	**DEVIANCE/DF**	**%DIFF**	**DELTA %**	**CHISQUARE**	**PR>CHI**	**AIC**
NULL	0.8328					
YEAR	0.8075	3.038	3.038	111.37	<.0001	3719.1856
YEAR+						
AREA	0.6418	22.935	19.897	582.61	<.0001	3154.5757
SALINITY	0.7455	10.483		217.94	<.0001	3507.2493
TEMP	0.7895	5.199		64.33	<.0001	3658.8551
SEASON	0.8045	3.398		11.86	0.0027	3711.3229
DO	0.8063	3.182		5.7	0.0578	3717.4824
YEAR+AREA+						
SALINITY	0.5992	28.050	5.115	149.97	<.0001	3010.6059
TEMP	0.6227	25.228		67.58	<.0001	3090.9911
SEASON	0.6387	23.307		12.15	0.0023	3146.4299
YEAR+AREA+SALINITY+						
TEMP	0.5814	30.187	2.137	62.59	<.0001	2952.0138
SEASON	0.597	28.314		8.74	0.0126	3005.8628
YEAR+AREA+SALINITY+TEMP+						

SEASON	0.5801	30.343	0.156	5.95	0.0511	2950.0653
MIXED MODEL	**AIC**					
YEAR+AREA+SALINITY+TEMP	10019.000					
YEAR+AREA+SALINITY+TEMP YEAR*AREA	**9754.500**					
YEAR+AREA+SALINITY+TEMP YEAR*SALINITY	10015.000					
YEAR+AREA+SALINITY+TEMP YEAR*TEMP	10019.000					
Proportion positive-Lognormal error distribution						
FACTOR	**DEVIANCE/DF**	**%DIFF**	**DELTA %**	**CHISQUARE**	**PR>CHI**	**AIC**
NULL	0.6806					
YEAR	0.6674	1.939	1.939	43.86	0.0287	1943.2249
YEAR+						
AREA	0.6544	3.850	1.910	24.89	0.0031	1936.3359
TEMP	0.6617	2.777		8.85	0.012	1938.3766
DO	0.6649	2.307		5.11	0.0778	1942.1189
SEASON	0.6681	1.837		0.22	0.6428	1945.0099
SALINITY	0.6697	1.602		0.44	0.9309	1948.7804
YEAR+AREA+						
TEMP	0.6504	4.437	0.588	6.96	0.0308	1933.3768
MIXED MODEL	**AIC**					
YEAR+AREA	**1940.3**					
YEAR+AREA YEAR*AREA	1940.8					

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
1982	750	0.010	0.22	0.006	0.39
1983	666	0.007	0.32	0.004	0.57
1984	671	0.006	0.28	0.006	0.30
1985	670	0.007	0.25	0.004	0.41
1986	760	0.021	0.16	0.023	0.15
1987	760	0.009	0.23	0.005	0.46
1988	760	0.012	0.19	0.013	0.19
1989	760	0.016	0.18	0.015	0.19
1990	760	0.014	0.19	0.009	0.31
1991	760	0.013	0.26	0.010	0.33
1992	760	0.006	0.31	0.002	0.86
1993	760	0.009	0.27	0.006	0.43
1994	760	0.008	0.29	0.006	0.39
1995	760	0.007	0.26	0.003	0.52
1996	800	0.007	0.26	0.008	0.22
1997	800	0.009	0.31	0.005	0.59
1998	800	0.007	0.25	0.005	0.32
1999	800	0.007	0.22	0.005	0.31
2000	780	0.010	0.19	0.010	0.19
2001	780	0.014	0.23	0.010	0.34
2002	780	0.009	0.24	0.005	0.43
2003	780	0.021	0.20	0.013	0.30
2004	780	0.015	0.21	0.007	0.44
2005	780	0.014	0.19	0.010	0.28
2006	780	0.010	0.20	0.007	0.28
2007	780	0.006	0.28	0.003	0.52
2008	780	0.015	0.16	0.007	0.32
2009	780	0.012	0.17	0.009	0.23
2010	780	0.012	0.22	0.006	0.44

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	1982	3.4
	1983	3.0
	1984	3.0
	1985	3.0
	1986	3.4
	1987	3.4
	1988	3.4
	1989	3.4
	1990	3.4
	1991	3.4
	1992	3.4
	1993	3.4
	1994	3.4
	1995	3.4
	1996	3.6
	1997	3.6
	1998	3.6
	1999	3.6
	2000	3.5
	2001	3.5
	2002	3.5
	2003	3.5
	2004	3.5
	2005	3.5
	2006	3.5
	2007	3.5
	2008	3.5
	2009	3.5
	2010	3.5
Area	1	10.2
	2	11.8
	3	11.8
	4	11.8
	5	11.8
	6	11.8
	7	11.8
	8	11.8
	9	5.2
	11	1.7
Season	Fall	49.8
	Spring	49.7
	Other	0.6
Temperature	<19.9	6.4
	20.0-29.9	76.9
	>30.0	16.7
Salinity	Fresh	8.7
	Estuarine	58.9
	Marine	25.8
	Hypersaline	6.6
Dissolved oxygen	Hypoxic	3.5
	Normoxic	85.0
	Hyperoxic	11.5

Figure 1. Distribution of sampling effort along Texas coast from 1982-2010 in terms of number of gillnet sets.

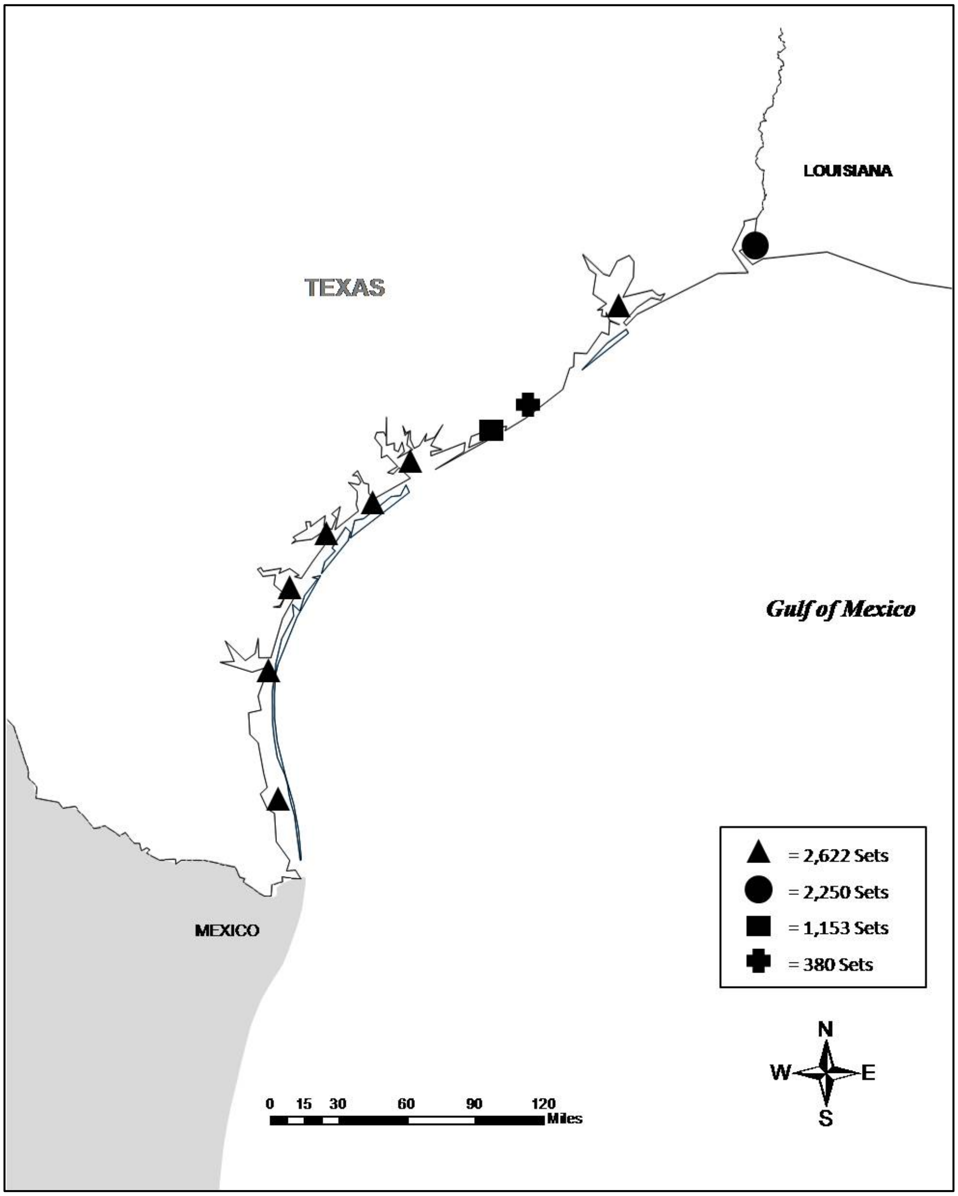
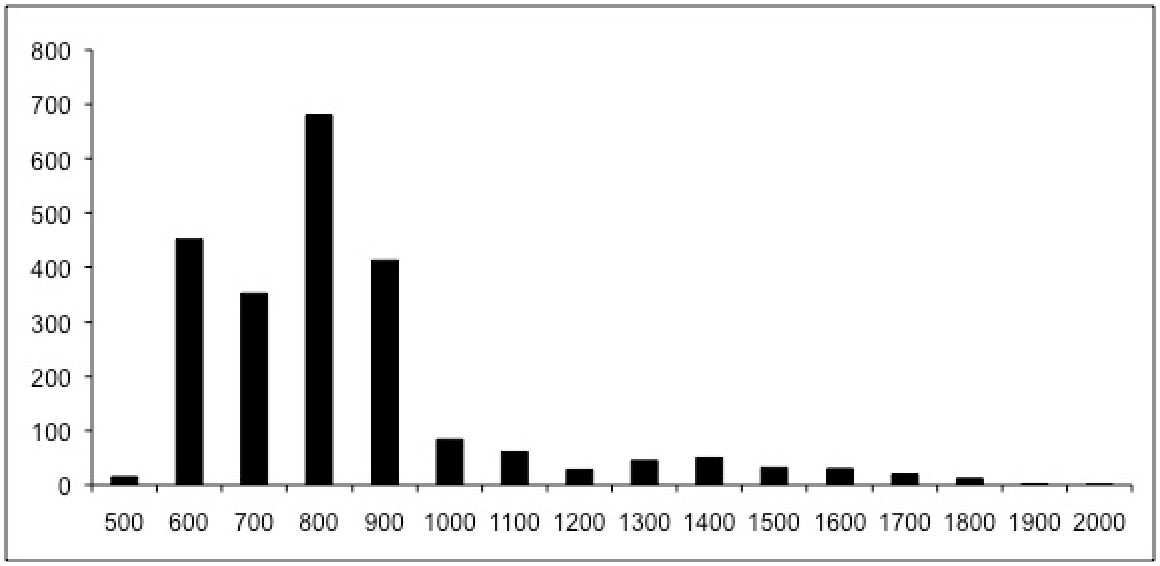


Figure 2. Frequency distribution of stretched total lengths (FL) and lengths by year for all blacktip sharks.



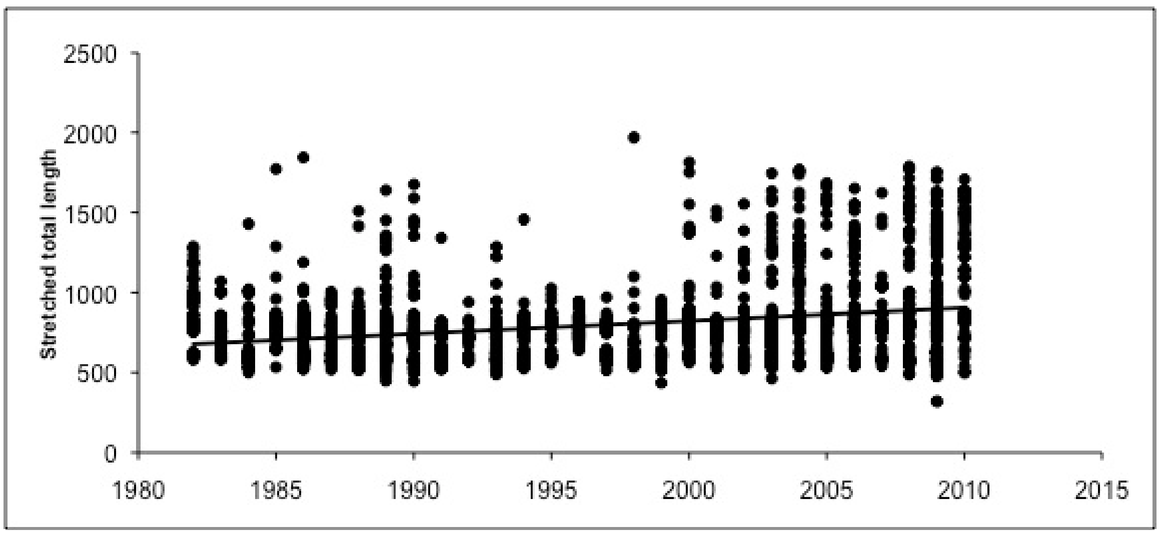


Figure 3. Nominal (obscpue) and standardized (STDCPUE) indices of abundance for all blacktip sharks. The dashed lines are the 95% confidence limits (LCL, UCL) for the standardized index. Each index has been divided by the maximum of the index.

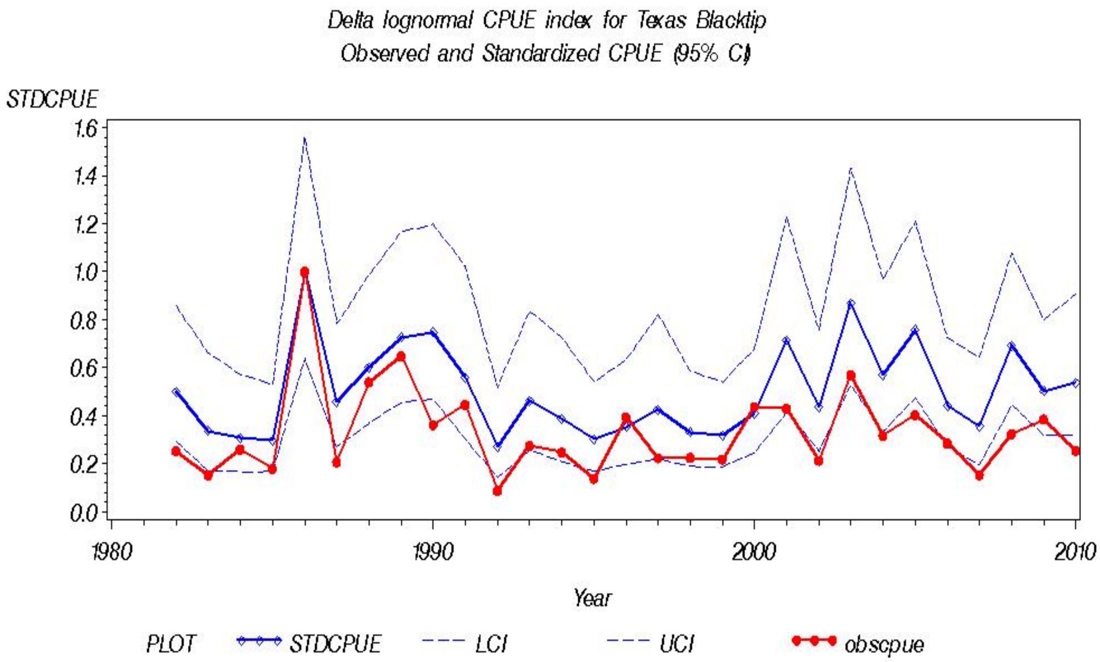
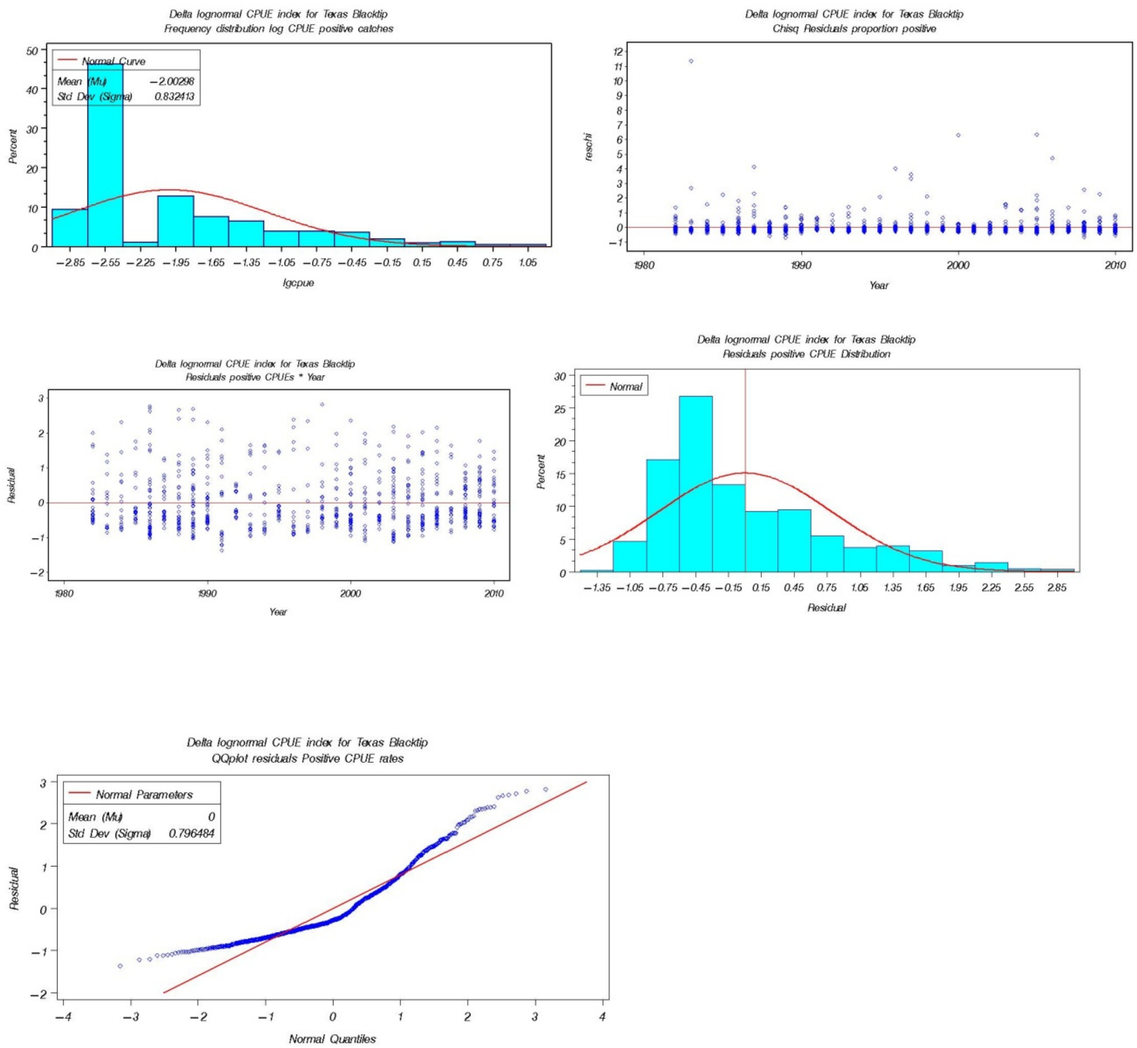


Figure 4. Diagnostic plots of the frequency distribution of residuals, quantile-quantile plots, and distribution of residuals by year.



Juvenile blacktips

A juvenile blacktip shark time series of abundance was constructed for all blacktip sharks from age 1 (>85 cm TL) to maturity (130 cm STL). The proportion positive of juvenile blacktips sharks was 0.9%.

The stepwise construction of the model is summarized in Table 3 and the index statistics can be found in Table 4. The standardized abundance index is shown in Figure 5 and the diagnostic plots assessing the fit of the models are shown in Figure 6.

Table 3. 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. Final models selected are in bold.

Proportion positive-Binomial error distribution						
FACTOR	**DEVIANCE/DF**	**%DIFF**	**DELTA%**	**CHISQUARE**	**PR>CHI**	**AIC**
NULL	0.3038					
YEAR	0.284	6.517	6.517	77.48	<.0001	1335.4084
YEAR+						
AREA	0.239	21.330	14.812	158.99	<.0001	1194.4181
SALINITY	0.2739	9.842		35.95	<.0001	1305.4551
DO	0.2822	7.110		6.99	0.0303	1332.4137
SEASON	0.2825	7.011		Negative of Hessian not positive definite.		1333.6271
TEMP	0.2827	6.945		5.26	0.0722	1334.1524
YEAR+AREA+						
SALINITY	0.2335	23.140		Negative of Hessian not positive definite.		1180.7154
DO	0.2375	21.824		5.42	0.0667	1193.0028
MIXED MODEL	**AIC**					
YEAR+AREA	**850.100**					
YEAR+AREA YEAR*AREA	2077.500					
Proportion positive-Lognormal error distribution						
FACTOR	**DEVIANCE/DF**	**%DIFF**	**DELTA%**	**CHISQUARE**	**PR>CHI**	**AIC**
NULL	0.2913					
YEAR	0.2955	-1.442	-1.442	26.31	0.5013	360.2412
YEAR+						
AREA	0.2929	-0.549	0.893	10.07	0.1844	353.8716
DO	0.2987	-2.540		0.18	0.9126	353.7623
SALINITY	0.296	-1.613		3.19	0.3636	352.7575
SEASON	0.2971	-1.991		0.11	0.7435	351.8382
TEMP	0.2963	-1.716		1.77	0.4117	352.1706
MIXED MODEL	**AIC**					
YEAR	**328.4**					

Table 4. 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
1982	750	0.00332	0.31	0.00314	0.33
1983	666	0.00118	0.60	0.00090	0.79
1984	671	0.00100	0.71	0.00084	0.85
1985	670	0.00064	0.60	0.00044	0.87
1986	760	0.00291	0.33	0.00240	0.41
1987	760	0.00182	0.44	0.00118	0.69
1988	760	0.00142	0.48	0.00100	0.69
1989	760	0.00239	0.44	0.00171	0.62
1990	760	0.00162	0.44	0.00109	0.66
1991	760			0.00000	
1992	760	0.00019	1.45	0.00013	2.15
1993	760	0.00060	0.71	0.00038	1.11
1994	760	0.00058	0.71	0.00038	1.10
1995	760	0.00105	0.53	0.00067	0.84
1996	800	0.00149	0.41	0.00094	0.65
1997	800	0.00028	0.91	0.00017	1.52
1998	800	0.00047	0.71	0.00028	1.21
1999	800	0.00122	0.48	0.00074	0.80
2000	780	0.00155	0.44	0.00141	0.49
2001	780	0.00053	0.71	0.00032	1.19
2002	780	0.00158	0.41	0.00095	0.69
2003	780	0.00155	0.41	0.00103	0.62
2004	780	0.00324	0.35	0.00236	0.48
2005	780	0.00191	0.39	0.00138	0.54
2006	780	0.00291	0.32	0.00200	0.46
2007	780	0.00099	0.60	0.00095	0.63
2008	780	0.00251	0.35	0.00157	0.56
2009	780	0.00311	0.27	0.00181	0.46
2010	780	0.00233	0.33	0.00140	0.55

Figure 5. Nominal (obscpue) and standardized (STDCPUE) indices of abundance for juvenile 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.

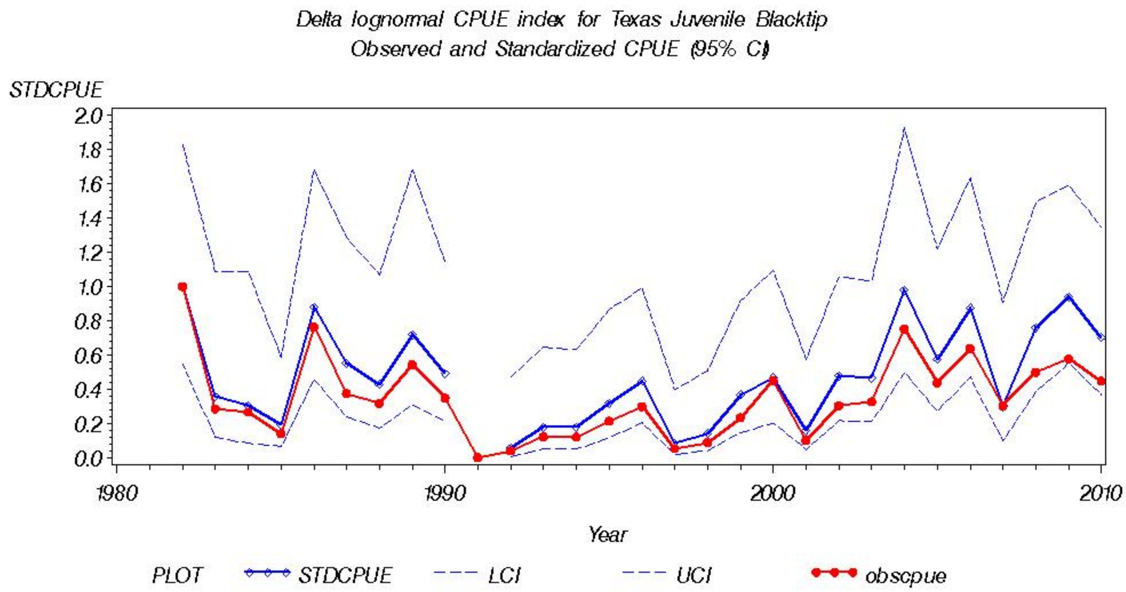


Figure 6. Diagnostic plots of the frequency distribution of residuals, quantile-quantile plots, and distribution of residuals by year for juvenile blacktips.