Catch rates and size distribution of blacknose shark *Carcharhinus acronotus* in the northern Gulf of Mexico, 2006-2009.

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Abstract

Blacknose sharks *Carcharhinus acronotus* are one of the most frequently caught sharks on a monthly longline survey initiated off the coast of Alabama in 2006. Between May 2006 and December 2009, 623 blacknose sharks (389 male, 234 female) were captured during 475 bottom longline sets. Nominal and modeled catch per unit effort (CPUE, sharks/100 hooks/hour) and length frequency distributions by sex are presented. Length frequency histograms indicate that the majority of blacknose sharks sampled are adults; in the case of males, the majority of the animals sampled are mature. Nominal CPUE was highest in 2006, and relatively consistent from 2007-2009. Monthly analysis of nominal mean CPUE showed bimodal peaks of occurrence. With the exception of 2008, trends in nominal and modeled CPUE were similar.

Introduction

In May 2006, the Dauphin Island Sea Lab (DISL), in conjunction with the National Marine Fisheries Service Mississippi Labs (NMFS MS Labs), initiated a monthly nearshore longline survey in Alabama coastal waters. Since its inception, several survey design changes have taken place, and ancillary surveys have been initiated to sample adjacent areas. Across all surveys, blacknose sharks *Carcharhinus acronotus* are one of the most common components. Between May 2006 and December 2009, 623 blacknose sharks (389 male, 234 female) were captured during 475 bottom longline sets. Nominal and modeled catch per unit effort (CPUE, sharks/100 hooks/hour) and length frequency distributions by sex are presented below.

Materials and Methods

DISL/NMFS cooperative survey

Nearshore bottom longline sampling for the DISL/NMFS cooperative survey began in May 2006 and employed a random stratified block design. Four blocks were established along the Mississippi/Alabama coast. Blocks 1 and 2 were located west of Mobile Bay (western blocks), and blocks 3 and 4 were located east of Mobile Bay (eastern blocks) (Figure 1A). Each block was 37 kilometers east to west and extended from the shoreline to approximately the 20 m isobath. Each month from May 2006 – February 2007, twelve stations were randomly chosen within a single block and evenly allocated across three depth strata (0-5 m, 5-10 m and 10-20 m). The survey design was modified from March 2007 through November 2008. During this period, six stations were selected at random each month within an eastern block, and six stations were selected at random within a western block. This survey modification ensured equal station dispersion within the block (two stations across each depth stratum), while always sampling one eastern and one western block each month.

DISL transect

In March 2007 a monthly transect survey was initiated (Figure 1B). This survey design extended sampling effort into Mobile Bay, while establishing a north to south time series to compliment the previously described east to west survey design. Each month, 12 stations were randomly selected, three in each of the four blocks.

DISL shark survey

In December 2008, four new blocks were established. These blocks encompassed the entire area of the previous two surveys, while extending coverage into Mississippi Sound (Figure 1C). Each month, three stations were randomly selected in each of the four blocks. To incorporate an offshore component, four times per year a line of longitude off the Alabama coastline was randomly selected, and six equidistant stations were sampled between 20 and 200 meters.

Sampling gear

While survey design changed throughout the history of this project, bait and gear have remained consistent throughout. At each station, a single bottom-longline was set and soaked for one hour. The main line consisted of 1.85 km (1 nm) of 4 mm monofilament (545 kg test) sampled with 100 gangions. Each gangion was made of 3.66 m of 3 mm (320 kg test) monofilament. Gangions consisted of a longline snap and a 15/0 circle hook, baited with Atlantic mackerel (*Scomber scombrus*). The longline was anchored to the bottom with weights at the start, middle and end of the mainline, and identified with buoys at each end. All sharks that could be safely boated were removed from the mainline, unhooked and identified to species. Biotic variables collected included sex, length (precaudal, fork, natural and stretch total), weight and maturity (when possible). Maturity in males was assessed following Clark and Von Schmidt (1965). Sharks were tagged in the primary dorsal fin with a plastic rototag. Abiotic variables collected included depth as well as surface and bottom values for temperature, salinity and dissolved oxygen using a Seabird SBE911 plus, or an SBE 25 CTD.

Analysis

All catch data from May 2006 through December 2009 were converted to CPUE, expressed as sharks/100 hooks/hour. Survey effort and CPUE by year are plotted in Figure 2. Length frequency histograms for blacknose sharks by sex are shown in Figure 3. To determine size at which 50% of the population of males was mature, a logistic model [$Y=1/(1+e^{-(a+bx)}$] was fitted to binomial maturity data using least squares nonlinear regression, where 0 = immature and 1 = mature. Median size at maturity was determined as –a/b (Mollet *et al*. 2000), where a = y-intercept and b = slope.

Nominal and standardized catch per unit effort were calculated for blacknose sharks captured between May 2006 and December 2009. Nominal mean monthly and yearly CPUE are shown in Figures 4 and 5, respectively. To model standardized CPUE, the delta-lognormal index of relative abundance (I_y) as described by Lo *et al*. (1992) and Ingram *et al*. (2010) was estimated as

(1) $$I_y = c_y p_y,$$

where c_y is the estimate of mean CPUE for positive catches only for year y; p_y is the estimate of mean probability of occurrence during year y. Both c_y and p_y were estimated using generalized linear models. Data used to estimate abundance for positive catches (c) and probability of occurrence (p) were assumed to have a lognormal distribution and a binomial distribution, respectively, and modeled using the following equations:

(2) $$\ln(\mathbf{c}) = \mathbf{X\beta} + \boldsymbol{\varepsilon}$$

and

(3) $$\mathbf{p} = \frac{e^{\mathbf{X\beta}+\boldsymbol{\varepsilon}}}{1 + e^{\mathbf{X\beta}+\boldsymbol{\varepsilon}}}$$, respectively,

where **c** is a vector of the positive catch data, **p** is a vector of the presence/absence data, **X** is the design matrix for main effects, **β** is the parameter vector for main effects, and **ε** is a vector of independent normally distributed errors with expectation zero and variance σ^2.

We used the GLIMMIX and MIXED procedures in SAS (v. 9.1, 2004) to develop the binomial and lognormal submodels, respectively. Similar covariates were tested for inclusion for both submodels: water depth category (10-m depth bins from 0 to 100 m; due to zero catch of blacknose at depths greater than 100 m, those stations were dropped), day-night (based on solar altitude at each station at the start time of the longline set: negative values indicate early morning and late evening, while positive values indicate times of full daylight), month and year. A backward selection procedure was used to determine which variables were to be included into each submodel based on type 3 analyses with a level of significance for inclusion of $\alpha = 0.05$. If year was not significant then it was forced into each submodel in order to estimate least-squares means for each year, which are predicted annual population margins (i.e., they estimate the marginal annual means as if over a balanced population).

Therefore, c_y and p_y were estimated as least-squares means for each year along with their corresponding standard errors, SE(c_y) and SE(p_y), respectively. From these estimates, I_y was calculated, as in equation (1), and its variance calculated as

(4) $$V(I_y) \approx V(c_y)p_y^2 + c_y^2 V(p_y) + 2c_y p_y \mathrm{Cov}(c, p),$$

where

(5) $$\mathrm{Cov}(c, p) \approx \rho_{c,p}\left[\mathrm{SE}(c_y)\mathrm{SE}(p_y)\right],$$

and $\rho_{c,p}$ denotes correlation of *c* and *p* among years.

The backward selection procedure used to develop the delta-lognormal model is summarized in Table 1 for blacknose shark. Figures 6 and 7 indicate the approximately normal distribution of the residuals of the binomial and lognormal submodels, respectively. Table 2 and Figure 8 summarize indices of blacknose shark developed from using a delta-lognormal model.

Results and Discussion

Despite changes in survey design between 2006 and 2009, the standardized methods employed allowed us to analyze all data combined, with no sampling artifacts. Despite the expansion of survey effort into Mobile Bay beginning in 2007 (Figure 2B-D), no blacknose sharks were ever sampled inside Mobile Bay. Conversely, as the survey expanded to include waters further offshore, our catch data from 2009 indicate that blacknose sharks are a common occurrence in waters deeper than 20 m (Figure 2D), supporting previously shown trends (Drymon *et al.* in revision).

The size at which fifty percent of the male blacknose sharks in our study are mature is 79.5 cm fork length; examining length frequency histograms demonstrates that the majority of male blacknose sharks sampled in our survey are mature. The lack of smaller blacknose sharks and the complete absence of neonates in our area is in agreement with previous studies that suggest the shallow waters off the Alabama coast serve no nursery function for this species (Parsons and Hoffmayer 2007).

Calculation of mean nominal CPUE for blacknose sharks showed both annual and interannual trends. Nominal CPUE was highest in 2006, but varied little between 2007 and 2009 (Figure 4). Our survey design allowed us to examine seasonal variation in mean nominal CPUE. Blacknose sharks were sampled during all months except January and February, and showed a bimodal trend in mean monthly nominal CPUE (Figure 5). Previous analysis indicates a weak relationship between abiotic variables and the shark community in our survey area (Drymon 2010), although this relationship warrants further investigation for blacknose sharks.

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Parsons, G.R. and E.R. Hoffmayer. 2007. Identification and characterization of shark nursery grounds along the Mississippi and Alabama gulf coasts. Pages 301-316 *in* C.T. McCandless, NE Kohler and HL Pratt Jr., editors. Shark nursery grounds of the Gulf of Mexico and east coast waters of the United States. American Fisheries Society, Symposium 50, Bethesda, Maryland.

Table 1: Summary of the backward selection procedure used to develop the delta-lognormal model for blacknose shark.

Run 1: Type 3 Tests of Fixed Effects for the Binomial Submodel

Effect	DF	Den DF	Square	F Value	Sq	Pr > F
year	3	83	6.73	2.24	0.0811	0.0894
month	9	83	18.56	2.06	0.0292	0.0422
dn	1	83	0.34	0.34	0.5598	0.5614
depthcat	4	83	29.56	7.39	<.0001	<.0001

Run 1: Type 3 Tests of Fixed Effects for the Lognormal Submodel

Effect	DF	Den DF	F Value	Pr > F
year	3	138	2.19	0.0921
month	9	138	2.2	0.0257
dn	1	138	0.84	0.361
depthcat	5	138	0.73	0.6018

Run 2: Type 3 Tests of Fixed Effects for the Binomial Submodel

Effect	DF	Den DF	Square	F Value	Sq	Pr > F
year	3	72	7.87	2.62	0.0487	0.057
month	9	72	20.75	2.31	0.0138	0.0244
depthcat	4	72	33.09	8.27	<.0001	<.0001

Run 2: Type 3 Tests of Fixed Effects for the Lognormal Submodel

Effect	DF	Den DF	F Value	Pr > F
year	3	147	2.23	0.0868
month	9	147	2.84	0.0042
dn	1	147	1.57	0.2118

Run 3: Type 3 Tests of Fixed Effects for the Binomial Submodel

Effect	DF	Den DF	Square	F Value	Sq	Pr > F
year	3	72	7.87	2.62	0.0487	0.057
month	9	72	20.75	2.31	0.0138	0.0244
depthcat	4	72	33.09	8.27	<.0001	<.0001

Run 3: Type 3 Tests of Fixed Effects for the Lognormal Submodel

Effect	DF	Den DF	F Value	Pr > F
year	3	148	2.19	0.0912
month	9	148	3.08	0.0021

Table 2: Abundance indices for blacknose shark.

Survey Year	*Frequency*	*N*	*Index*	*Scaled Index*	*Scaled Nominal*	*CV*	*Scaled LCL*	*Scaled UCL*
2006	0.5161	93	3.5725	1.4960	1.6532	0.1758	1.0555	2.1206
2007	0.3243	148	1.9996	0.8374	0.8569	0.2325	0.5293	1.3249
2008	0.2482	137	2.7358	1.1457	0.7499	0.2532	0.6959	1.8861
2009	0.3444	90	1.2439	0.5209	0.7400	0.2450	0.3214	0.8443

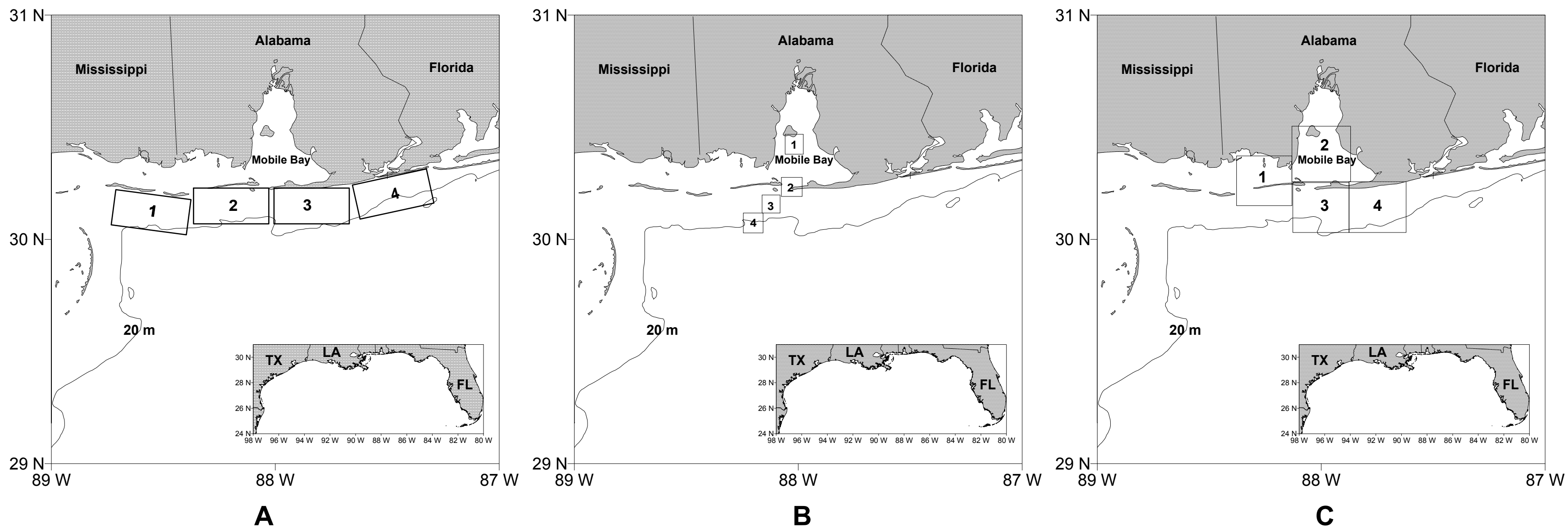


Figure 1: Description of the survey design for the A) DISL/NMFS cooperative longline survey, B) DISL transect survey and C) DISL shark survey.

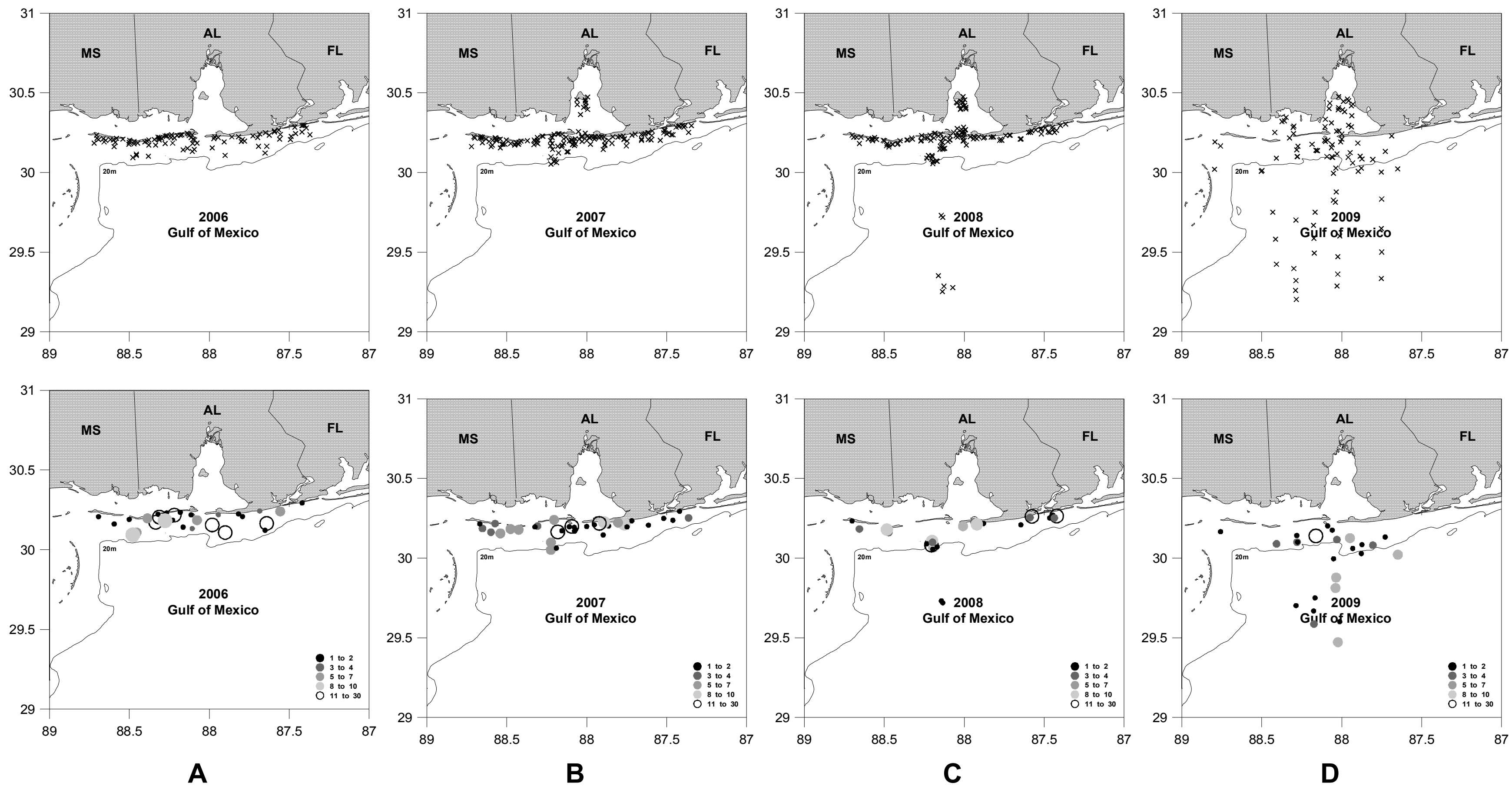


Figure 2: Effort (top panel) and CPUE (bottom panel, sharks/100 hooks/hour) for the years A) 2006, B) 2007, C) 2008 and D) 2009.

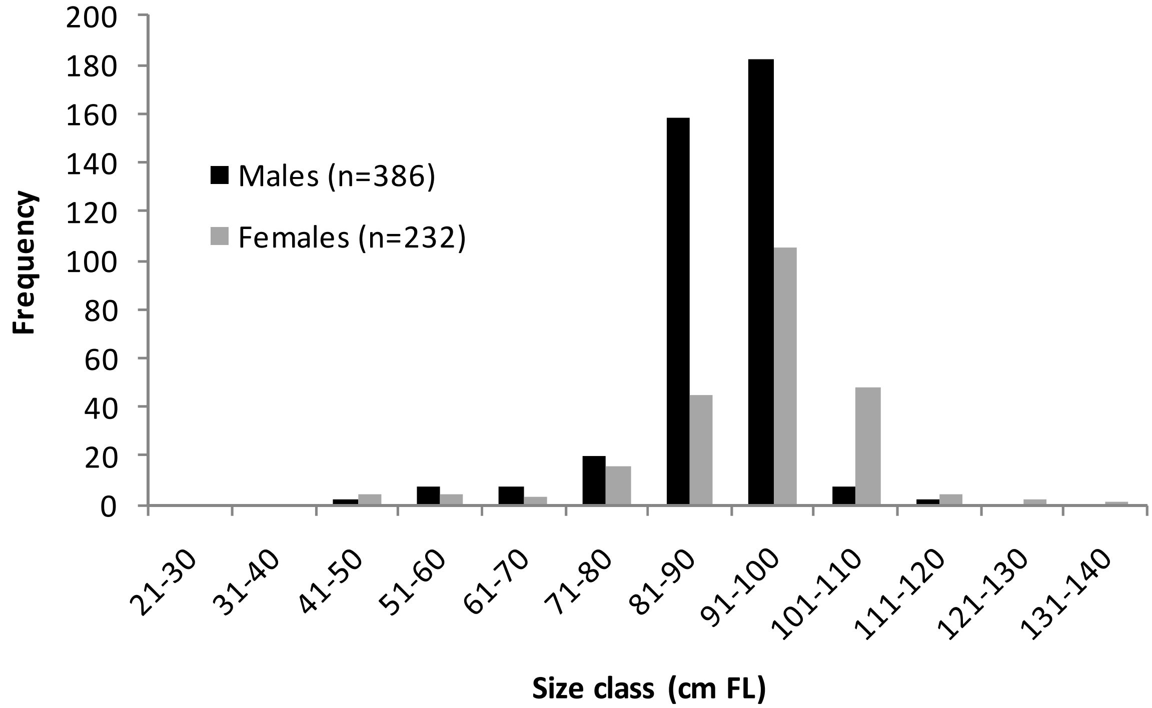


Figure 3: Size frequency histograms for male and female blacknose sharks, 2006-2009.

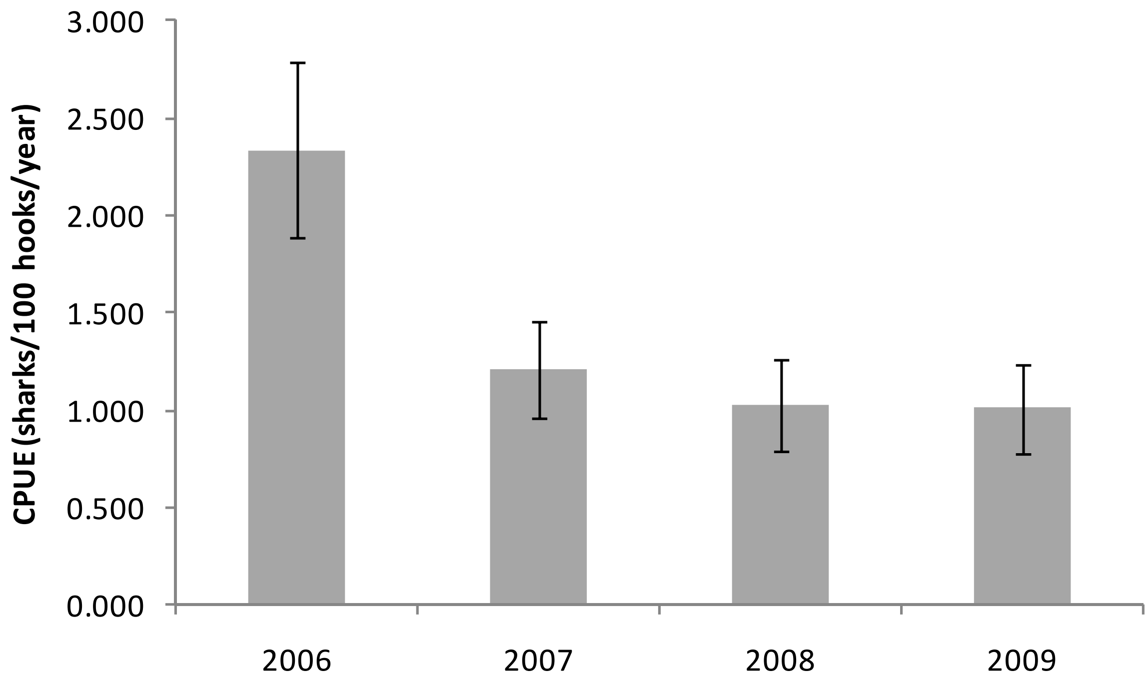


Figure 4: Nominal CPUE (sharks/100 hooks/hour) per year for blacknose shark. Error bars are ± SE.

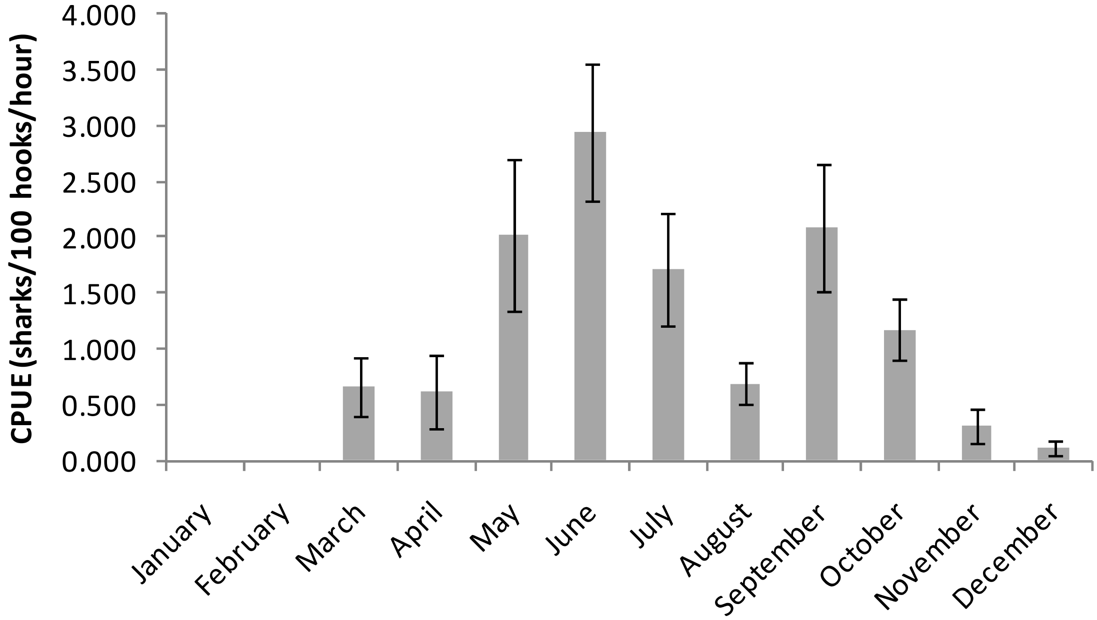
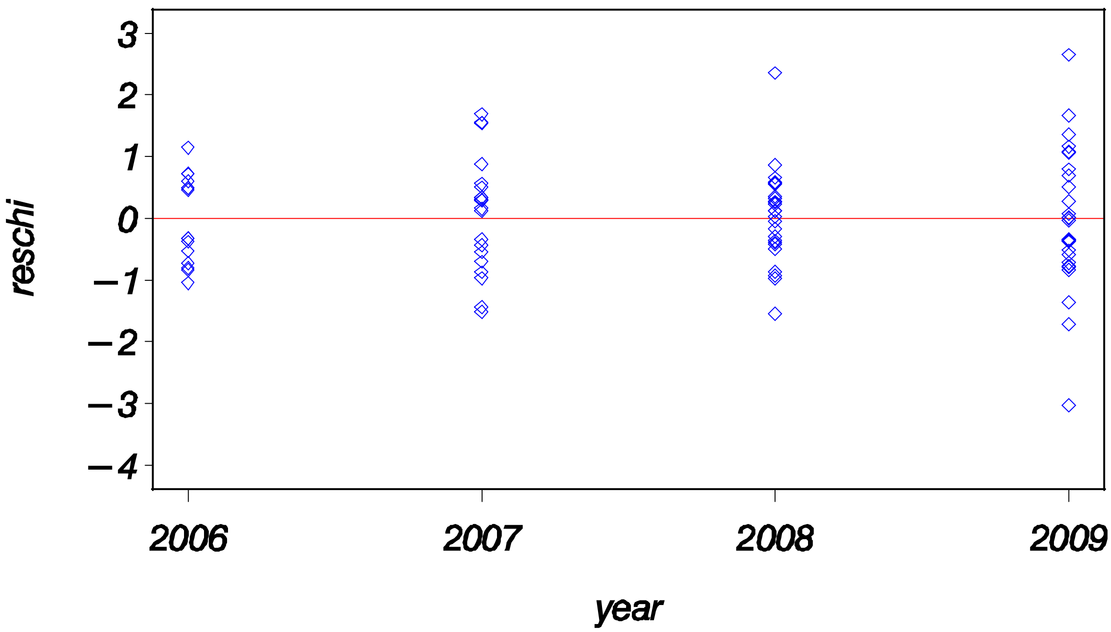


Figure 5: Nominal CPUE (sharks/100 hooks/hour) for blacknose shark (sexes combined) per month, 2006-2009. Error bars are ± SE. No blacknose sharks were ever encountered during January or February.



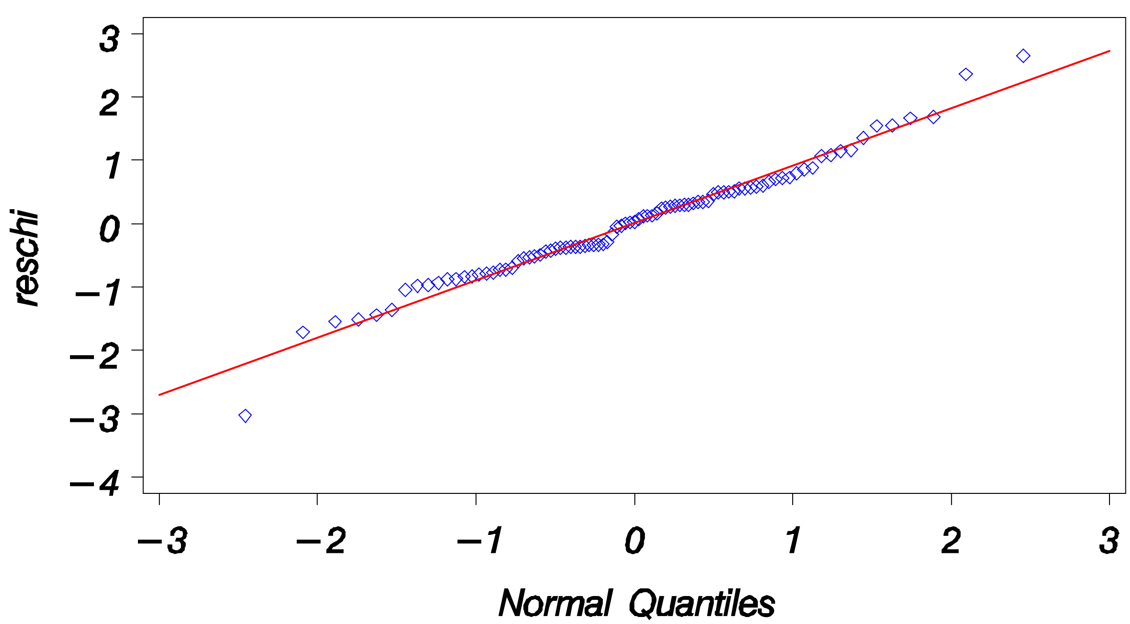
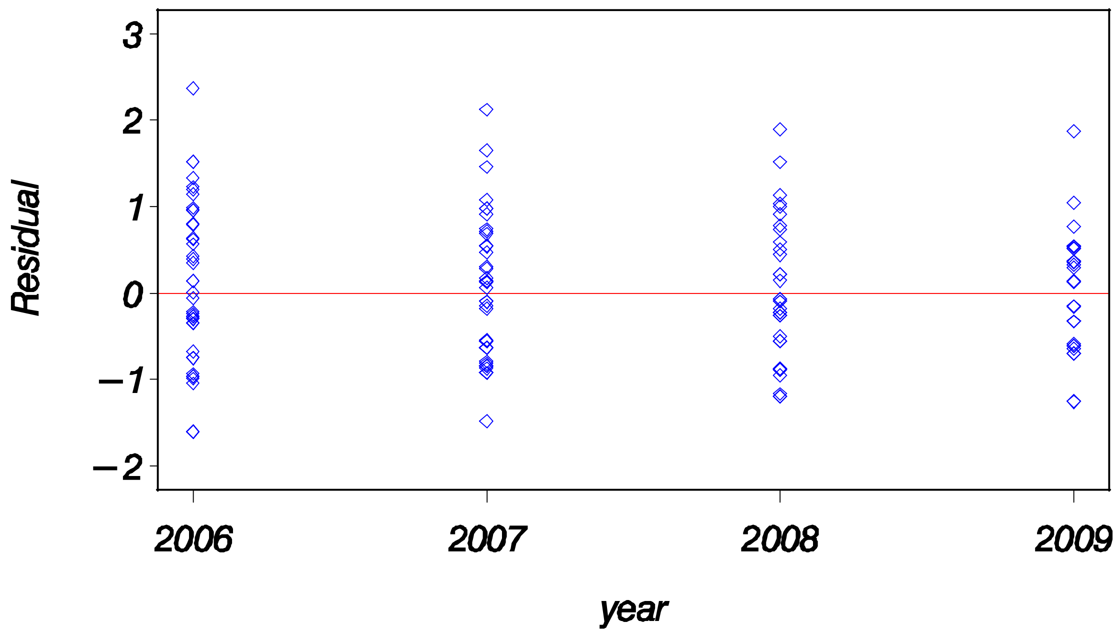


Figure 6: Residual plots for the binomial submodel. The top plot is of residuals by year, while the bottom is a QQ-plot of the residuals.



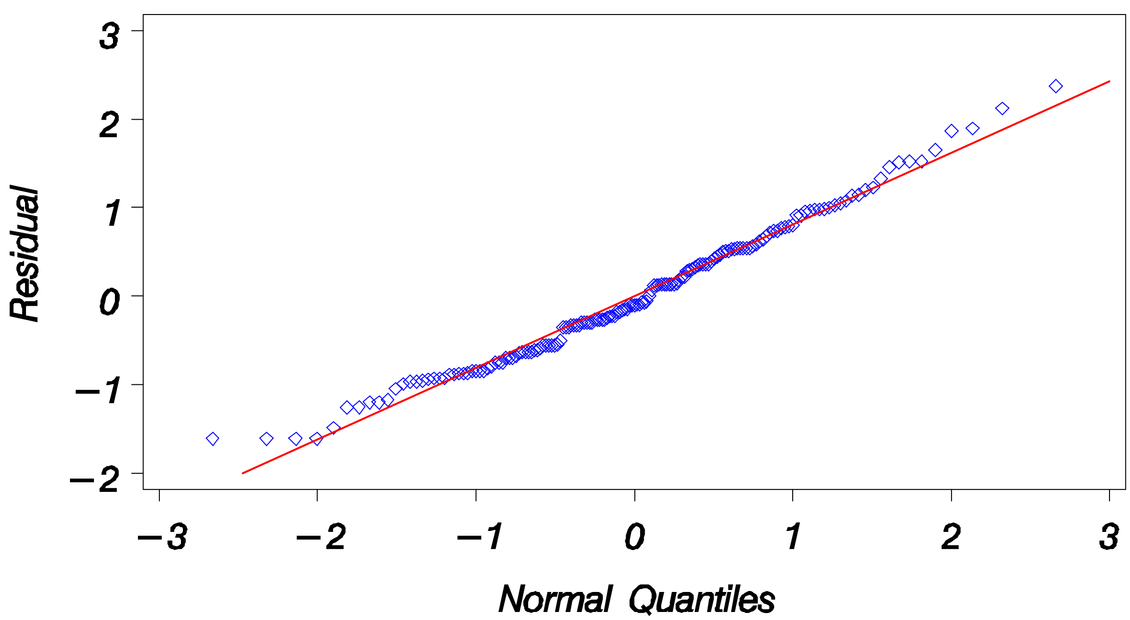


Figure 7: Residual plots for the lognormal submodel. The top plot is of residuals by year, while the bottom is a QQ-plot of the residuals.

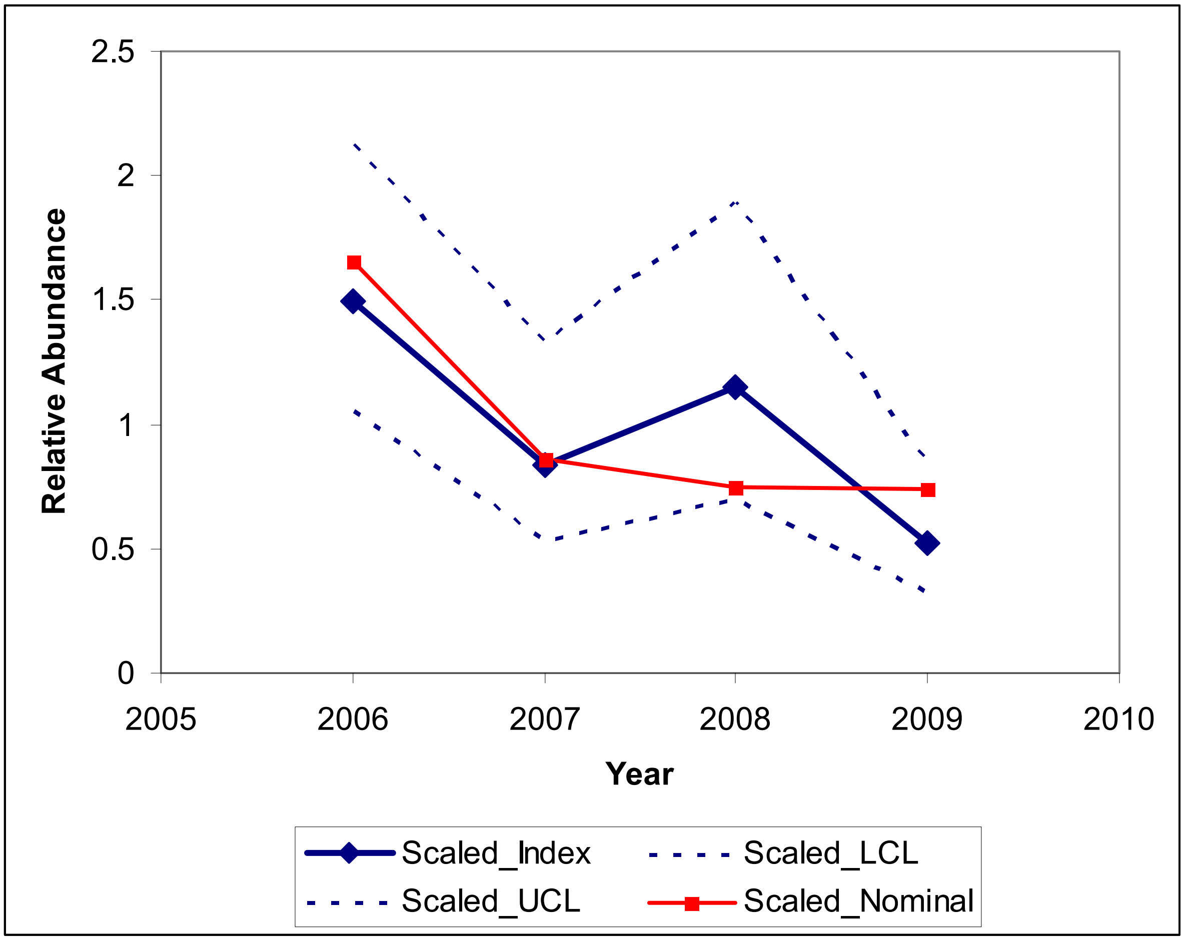


Figure 8: Abundance indices of blacknose shark.

ANNEX

The delta-lognormal index of relative abundance (I_y) as described by Lo *et al*. (1992) and Ingram *et al*. (2010) was employed to develop a second time series of abundance for blacknose shark using the DISL BLL data. We used the GLIMMIX and MIXED procedures in SAS (v. 9.1, 2004) to develop the binomial and lognormal submodels, respectively. Similar covariates were tested for inclusion for both submodels: water depth (5-m depth bins from 0 to 20 m), month and year. Stations greater than 20 m were excluded from analysis due to low sample size and lack of time series. Those stations north of 30.2 N latitude were excluded because they occurred in waters not inhabited by blacknose sharks. A backward selection procedure was used to determine which variables were to be included in each submodel based on type 3 analyses with a level of significance for inclusion of $\alpha = 0.05$. If year was not significant then it was forced into each submodel in order to estimate least-squares means for each year, which are predicted annual population margins (i.e., they estimate the marginal annual means as if over a balanced population).

The results indicate that after data reduction the original trend remains. However, now the trend of nominal indices follows more closely the trend of the modeled indices.

INGRAM G. W., JR., W. J. Richards, J. T. Lamkin and B. Muhling. 2010. Annual indices of Atlantic bluefin tuna (*Thunnus thynnus*) larvae in the Gulf of Mexico developed using delta-lognormal and multivariate models. Aquat. Living Resour. 23:35–47.

LO, N. C. H., L.D. Jacobson, and J.L. Squire. 1992. Indices of relative abundance from fish spotter data based on delta-lognormal models. Can. J. Fish. Aquat. Sci. 49: 2515-2526.

Table A1. The summary of the backward selection procedure used to develop the delta-lognormal model for blacknose shark.

Run 1: ***Type 3 Tests of Fixed Effects for the Binomial Submodel***

Effect	*Num DF*	*Den DF*	*Chi-Square*	*F Value*	*Pr > ChiSq*	*Pr > F*
year	3	80	11.28	3.76	0.0103	0.0140
month	8	80	15.77	1.97	0.0459	0.0608
depthcat	3	80	33.79	11.26	<.0001	<.0001

Run 1: ***Type 3 Tests of Fixed Effects for the Lognormal Submodel***

Effect	*Num DF*	*Den DF*	*F Value*	*Pr > F*
year	3	115	1.75	0.1613
month	8	115	1.85	0.0743
depthcat	3	115	2.19	0.0926

Run 2: ***Type 3 Tests of Fixed Effects for the Binomial Submodel***

Effect	*Num DF*	*Den DF*	*Chi-Square*	*F Value*	*Pr > ChiSq*	*Pr > F*
year	3	80	11.28	3.76	0.0103	0.0140
month	8	80	15.77	1.97	0.0459	0.0608
depthcat	3	80	33.79	11.26	<.0001	<.0001

Run 2: ***Type 3 Tests of Fixed Effects for the Lognormal Submodel***

Effect	*Num DF*	*Den DF*	*F Value*	*Pr > F*
year	3	122	1.50	0.2172
month	8	122	2.10	0.0411

Table A2. Abundance indices of blacknose shark.

Survey_Year	*Frequency*	*N*	*_Index*	*Scaled_Index*	*Scaled_Nominal*	*CV*	*Scaled_LCL*	*Scaled_UCL*
2006	0.51087	92	2.60730	1.92036	1.62570	0.24655	1.18136	3.12163
2007	0.35115	131	1.34004	0.98698	0.93461	0.30785	0.54068	1.80167
2008	0.22609	115	1.03215	0.76021	0.65330	0.36994	0.37141	1.55601
2009	0.32609	46	0.45138	0.33245	0.78638	0.55653	0.11764	0.93952

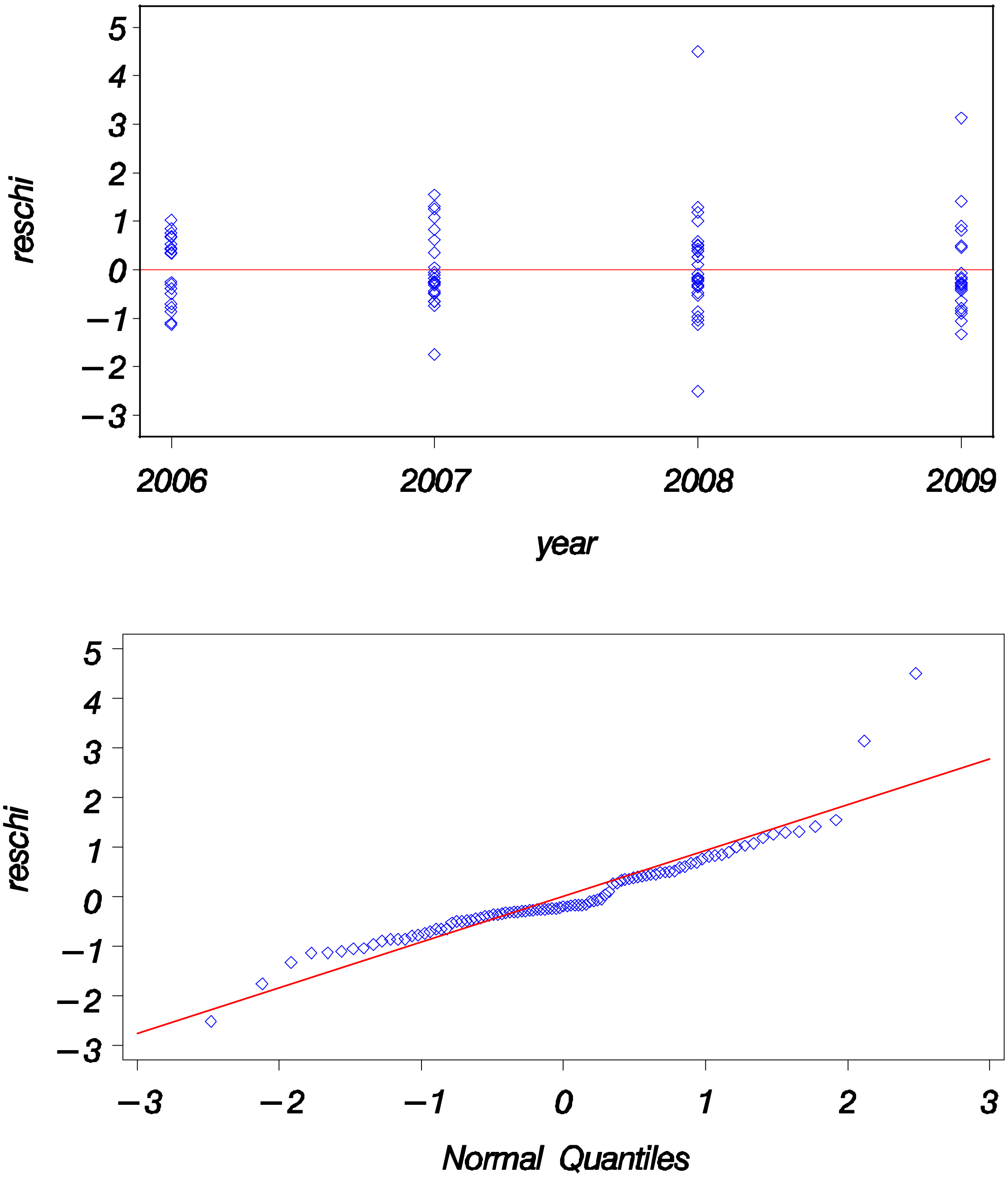


Figure A1. Residual plots for the binomial submodel. The top plot is of residuals by year, while the bottom is a QQ-plot of the residuals.

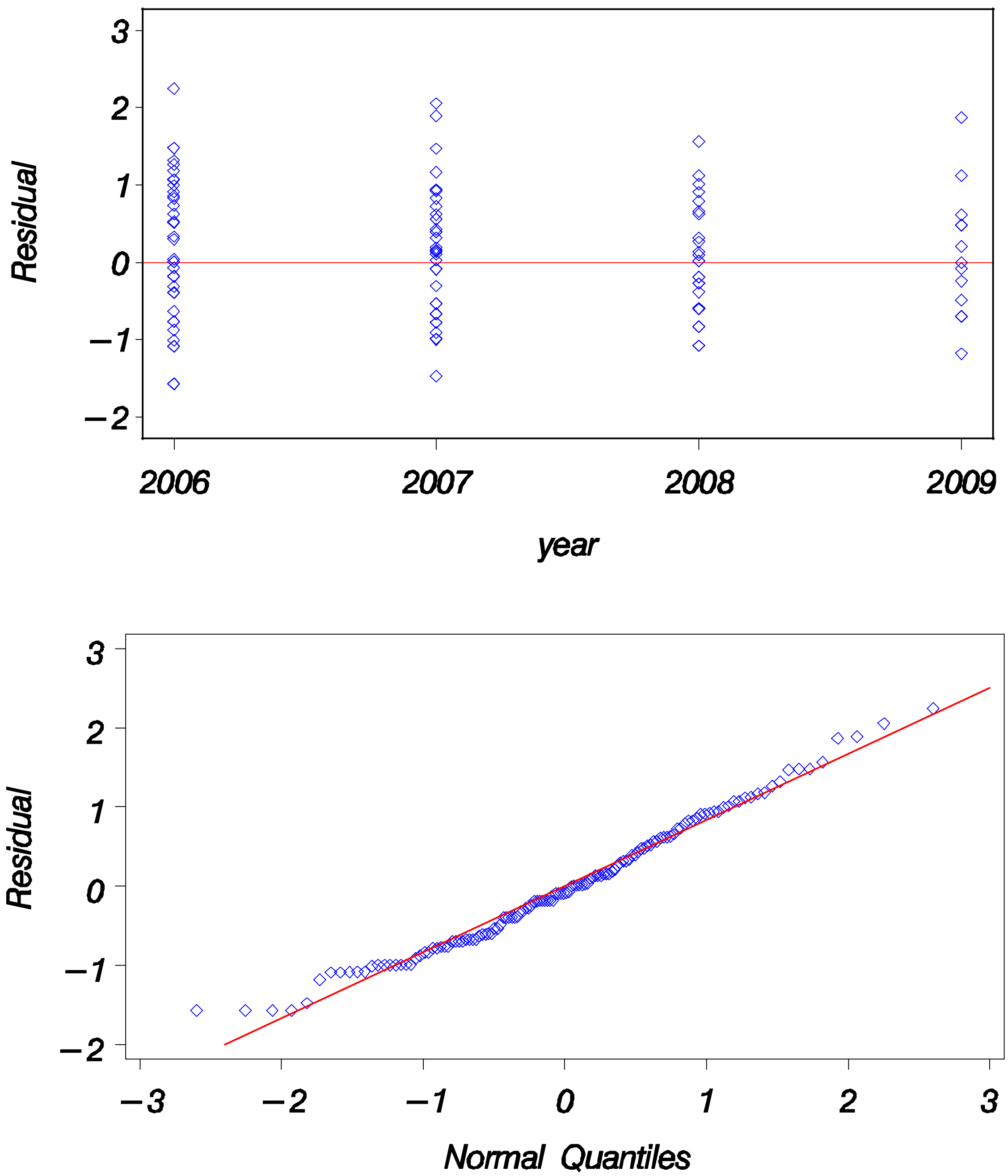


Figure A2. Residual plots for the lognormal submodel. The top plot is of residuals by year, while the bottom is a QQ-plot of the residuals.

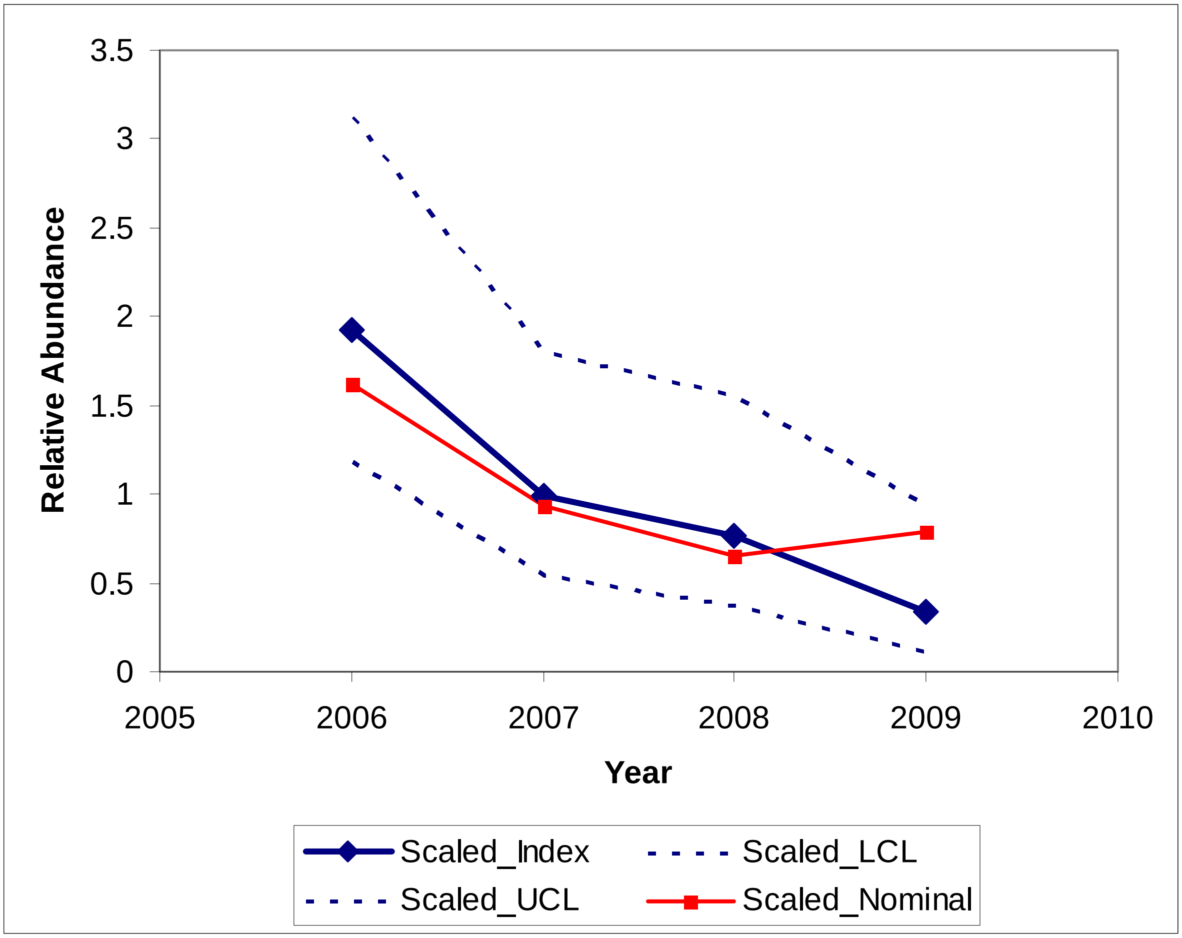


Figure A3. Abundance indices of blacknose shark.