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INTRODUCTION

Fishery-independent surveys of coastal shark populations have taken place since 1994 in the eastern and northern Gulf of Mexico. The cooperative Gulf of Mexico Shark Pupping and Nursery (GULFSPAN) survey began in 1996 to examine the distribution and abundance of juvenile sharks in coastal areas. 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 Act. NOAA Fisheries Panama City Laboratory oversees the survey. In 2003, Gulf Coast Research Laboratory at the University of Southern Mississippi was added to the survey. In 2007, additional participants included the Florida Natural History Museum at the University of Florida and Dauphin Island Sea Laboratory at the University of South Alabama. In 2008, the Florida State University Coastal and Marine Laboratory became a collaborator. In 2016 and 2017, New College of Florida and Havenworth Coastal Conservation became collaborators in the GULFSPAN project, respectively. Herein, we develop a relative abundance index for young-of-the-year scalloped hammerhead shark based on data collected from these surveys.

MATERIAL AND METHODS

GULFSPAN Survey Field Data Collection

From 1996-2005, a 186-m long gill net consisting of six different mesh size panels was used 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 SM, 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 monofilament net with 7.6 cm (3.0”) SM was added to the sampling gear and the 20.3 cm SM panel was removed. Previous analysis has found the addition of the 7.6 cm SM panel and the removal of the 20.3 SM panel did not affect shark catch rates.

Surveys were conducted monthly from April-October, occasionally March-November. Depending on institution and area, gillnet set locations were either fixed or chosen randomly within each area based on depth strata and GPS location, based on a spatially-balanced sampling design, or randomly selected using Hawth’s Tools extension for ArcMap. 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).

Index Development

Preliminary examination of the data indicated the occurrence of scalloped hammerhead was highest in the northern Gulf of Mexico for the NOAA and University of Southern Mississippi surveys. While the other surveys did capture scalloped hammerhead, the frequency of capture

(<1%) was too low to develop a reliable index and these surveys were excluded. Several categorical and continuous variables were constructed for analysis of the survey data.

"Year" (25 levels): 1996-2019

"Area" (5 levels): locations of gillnet set major areas
Apalachicola Bay, including St. Vincent Island
Mississippi Sound
St. Andrews Bay
Crooked Island Sound
St. Joe Bay

"Survey" (2 levels): Laboratory conducting the survey
NOAA Fisheries Service
University of Southern Mississippi

"Season" (4 levels):
Spring=Mar-May
Summer=Jun-Aug Fall=Sep-Nov
Winter=Dec-Feb

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

Time of Day (4 levels)
Night= 2201-400
Dawn= 0401-1000
Day=1001-16000
Dusk=1601-2200

Temperature, Salinity, Dissolved Oxygen, Turpidity (Continuous variables)

Indices of abundance were initially attempted to be developed 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 and the positive catches modeled assuming a lognormal distribution with a normal link function. However, despite the proportion positives being relatively high (5.1%), the binomial model would not converge. Indices of abundance were therefore developed within a generalized linear mixed model where catch per unit effort (number of shark caught per hour) was assumed to follow a lognormal distribution (Maunder and Punt 2004).

RESULTS AND DISCUSSION

The location of the sampling areas for the NOAA and USM surveys is in Figure 1. The stepwise construction of the lognormal model is summarized in Table 1. The index values 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 the average of their respective index. Diagnostic plots assessing the fit of the models were deemed acceptable (Figure 3).

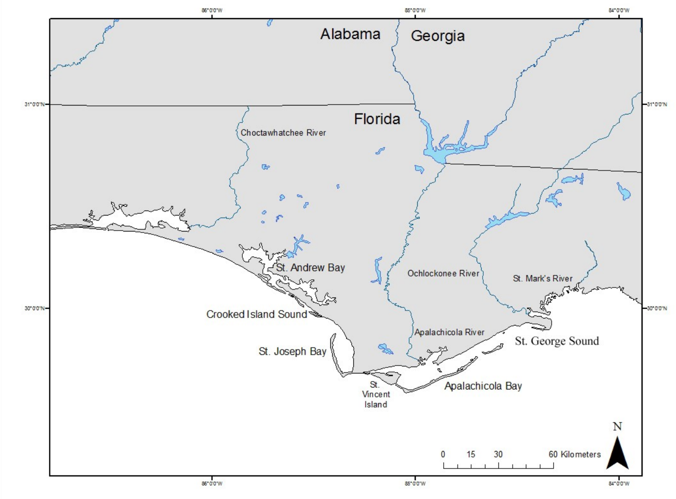
Table 1. Analysis of deviance of explanatory variables for the lognormal generalized linear formulations of the proportion of positive and positive catches for scalloped hammerhead

Lognormal error distribution					
FACTOR	**DEVIANCE/DF**	**%DIFF**	**DELTA%**	**CHISQUARE**	**PR>CHI**
NULL	1.0124				
YEAR	0.8536	15.685	15.685	81.4	<.0001
YEAR+					
AREA	0.7524	25.682	9.996	47.96	<.0001
SURVEY	0.7889	22.076		27.62	<.0001
SEASON	0.8217	18.836		14.96	0.0006
TURBIDITY	0.8218	18.827		0.27	0.6032
SETDEPTH	0.826	18.412		12.13	0.0005
SALINITY	0.8284	18.175		9.7	0.0018
TEMPERATURE	0.8292	18.096		19.32	<.0001
TIME	0.8386	17.167		9.2	0.0268
DO	0.8953	11.567		0.89	0.3448
YEAR+AREA+					
SEASON	0.7101	29.860	4.178	21.67	<.0001
TEMPERATURE	0.73	27.894		20.71	<.0001
TIME	0.7376	27.143		9.96	0.0189
SETDEPTH	0.7422	26.689		5.66	0.0174
SALINITY	0.7552	25.405		0.03	0.874
SURVEY	*				
YEAR+AREA+SEASON+					
TIME	0.6942	31.430	1.571	10.95	0.012
SETDEPTH	0.7049	30.373		3.59	0.0581
TEMPERATURE	0.724	28.487		4.32	0.0377
MIXED MODEL	**AIC**				
YEAR+AREA+SEASON	844.9				
YEAR*AREA	845.5				
YEAR*SEASON	846.9				

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

Year	Nominal	Standard error	N	Standardized Index	LCL	UCL	CV
1996	0.010	0.003	134	0.009	0.005	0.017	0.294
1997	0.018	0.007	138	0.016	0.007	0.039	0.461
1998	0.002	0.001	151	0.002	0.001	0.006	0.548
1999	0.109	0.028	144	0.091	0.049	0.167	0.312
2000	0.172	0.040	114	0.156	0.095	0.257	0.253
2001	0.162	0.045	236	0.148	0.082	0.268	0.302
2002	0.230	0.025	319	0.150	0.108	0.209	0.166
2003	0.108	0.018	401	0.102	0.071	0.146	0.181
2004	0.069	0.016	274	0.070	0.044	0.109	0.227
2005	0.034	0.018	276	0.048	0.023	0.098	0.373
2006	0.065	0.017	306	0.079	0.051	0.122	0.220
2007	0.189	0.029	335	0.168	0.120	0.237	0.171
2008	0.165	0.032	327	0.172	0.118	0.250	0.189
2009	0.204	0.033	229	0.163	0.110	0.242	0.200
2010	0.276	0.044	202	0.208	0.137	0.316	0.211
2011	0.123	0.032	321	0.159	0.107	0.237	0.201
2012	0.095	0.020	287	0.093	0.061	0.143	0.217
2013	0.149	0.028	274	0.129	0.084	0.198	0.215
2014	0.124	0.029	277	0.141	0.093	0.212	0.207
2015	0.091	0.017	264	0.068	0.041	0.112	0.252
2016	0.131	0.029	277	0.124	0.078	0.197	0.235
2017	0.206	0.037	295	0.184	0.124	0.273	0.200
2018	0.214	0.047	237	0.210	0.135	0.328	0.225
2019	0.204	0.047	223	0.176	0.105	0.297	0.265

Figure 1. Location of sampling areas for the NOAA and University of Southern Mississippi surveys.



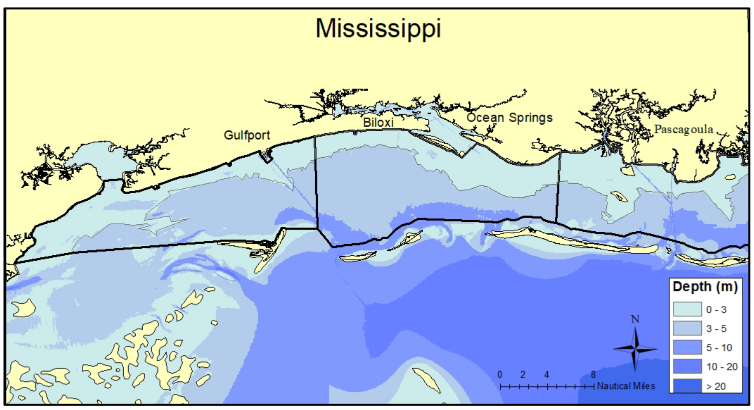


Figure 2. Nominal and standardized indices of abundance for scalloped hammerhead. The dashed lines are the 95% confidence limits for the standardized index. Each index has been divided by the mean of the index.

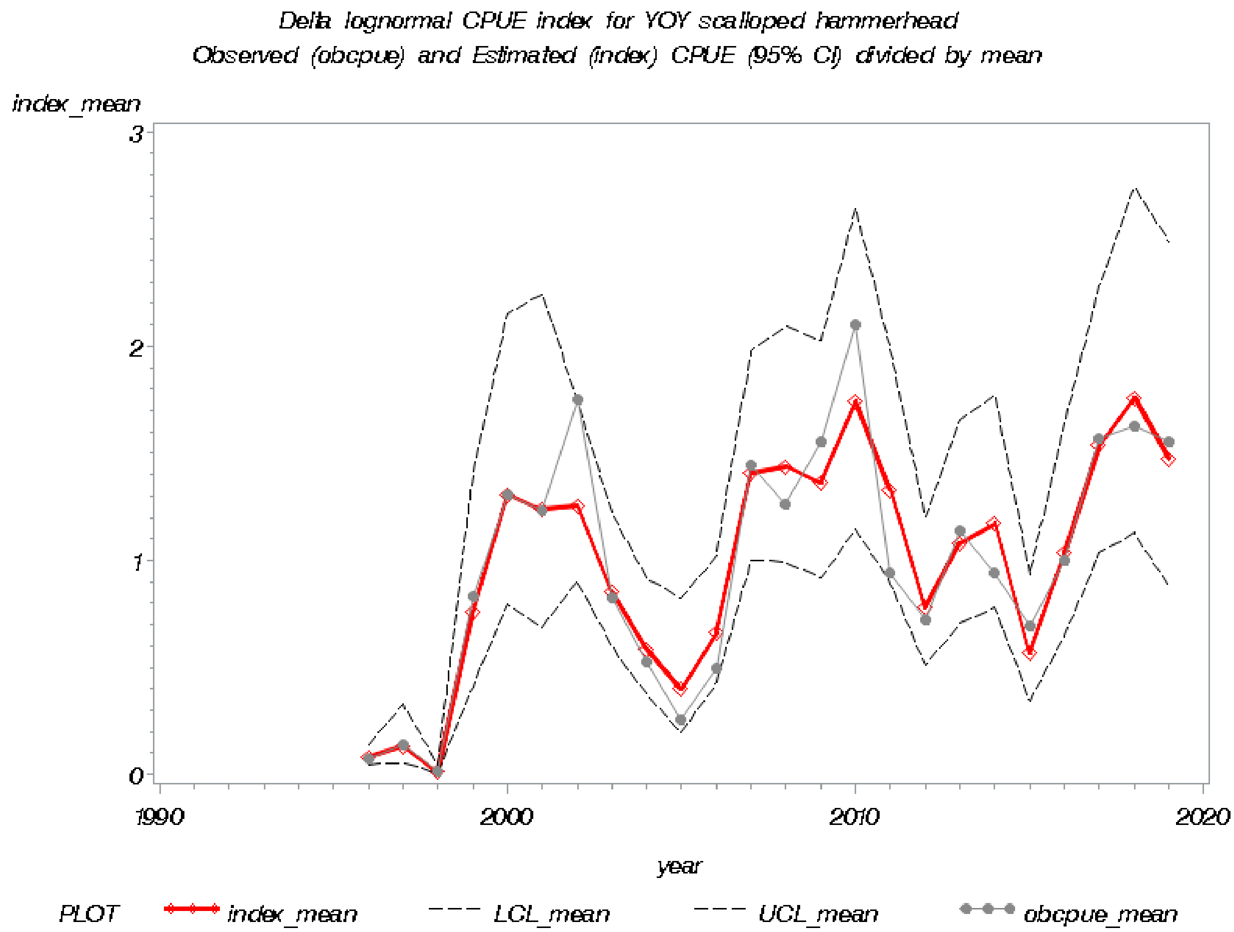
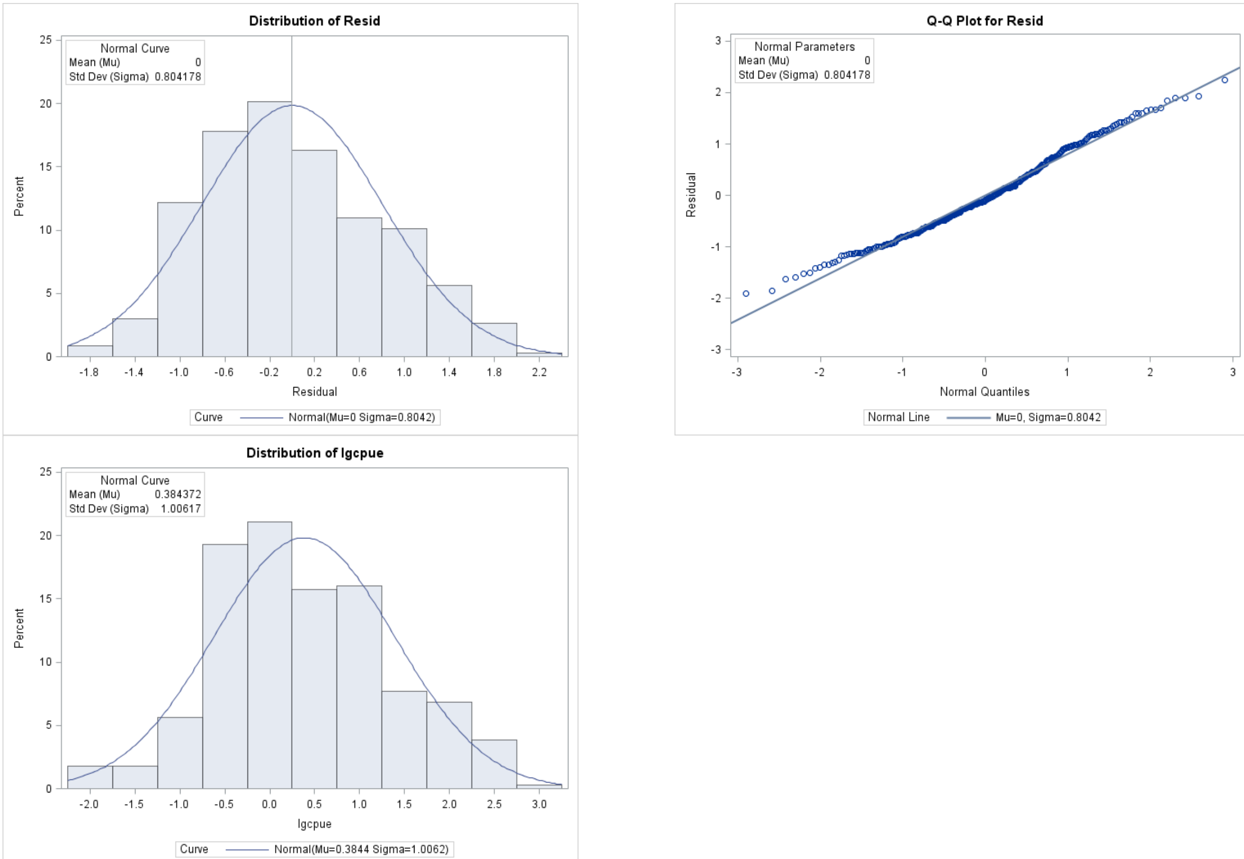


Figure 3. Diagnostic plots of the model outputs for scalloped hammerhead.



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