Standardized abundance indices from scalloped and great hammerhead from the Shark Bottom Longline Observer Program, 1994-2019

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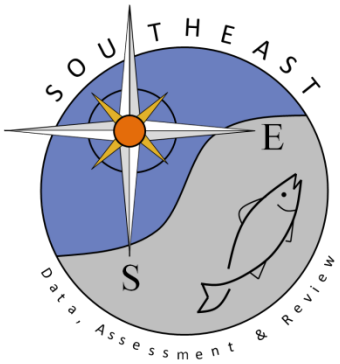

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Introduction

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. Morgan et al. 2009, Mathers et al. 2018 and references therein). Previous stock assessments for sharks utilized data from this fishery as an index of abundance and as an input to the stock assessment model. Herein, we abundance time series index for scalloped and great hammerhead shark.

Methods

Catch rate analysis

A combined data set was developed based on observer programs from Morgan et al. (2009) and Mathers et al. (2018). Historically, vessels in this fishery primarily targeted sandbar shark and fish from North Carolina to the eastern Gulf of Mexico (Figure 1). With the introduction of the shark research fishery in 2008, vessels outside the research fishery were not permitted to target or land sandbar sharks. This change in management regulations likely influences the time series of abundance for sharks such that vessels fishing in the research fishery should be modeled separately from those outside the research fishery. Therefore, indices of abundance were created from this data series; 1994-2007 for all vessels and 2008-2019 for vessels in the research fishery. Following the definition of the south Atlantic and Gulf of Mexico by the Highly Migratory Species Division, abundance trends were developed for the Atlantic Ocean, Gulf of Mexico and all areas. Following recommendations of the data workshop, indices were developed for scalloped hammerhead for all areas, Atlantic Ocean and Gulf of Mexico. Indices were only developed for great hammerhead shark for all areas combined.

For the purposes of analysis, several categorical variables were considered:

- "Year"
  1994-2007- Non-research fishery
  2008-2019- Research fishery only

- "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
  Circle hook
  J style hook
  Undefined

- "Bait type": the bait that was used by the majority of the set
  Shark (Elasmobranchii)
  Teleost
  Other (undefined or multiple bait types)

- "Soak": time from when the first hook was set until the first hook was removed during haulback

Following previous methods in multiple SEDARs, 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:

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

Factors most likely to influence the probability of capturing a hammerhead shark were evaluated in a forward stepwise fashion (e.g. Ortiz and Arocha 2004, Cortés et al. 2007, Brodziak and Walsh 2013). 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 factor. Each factor was ranked from the relative greatest to least reduction in deviance per degree of freedom when compared to the null model:

$$\%Dev_t = 100*(Dev_{null}-Dev_f)/\ Dev_{null}$$

where $\%Dev_t$ = the percentage of reduction in deviance explained by the addition of each factor, Dev_{null} =the deviance per degree of freedom from the null model, and Dev_f =the deviance per degree of freedom due to the addition of a factor.

The factor with the greatest reduction in deviance was then incorporated into the model providing the effect was significant ($p \leq 0.05$) 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. All analysis was conducted using the SAS statistical computer software (version 9.4) with the PROC GENMOD procedure.

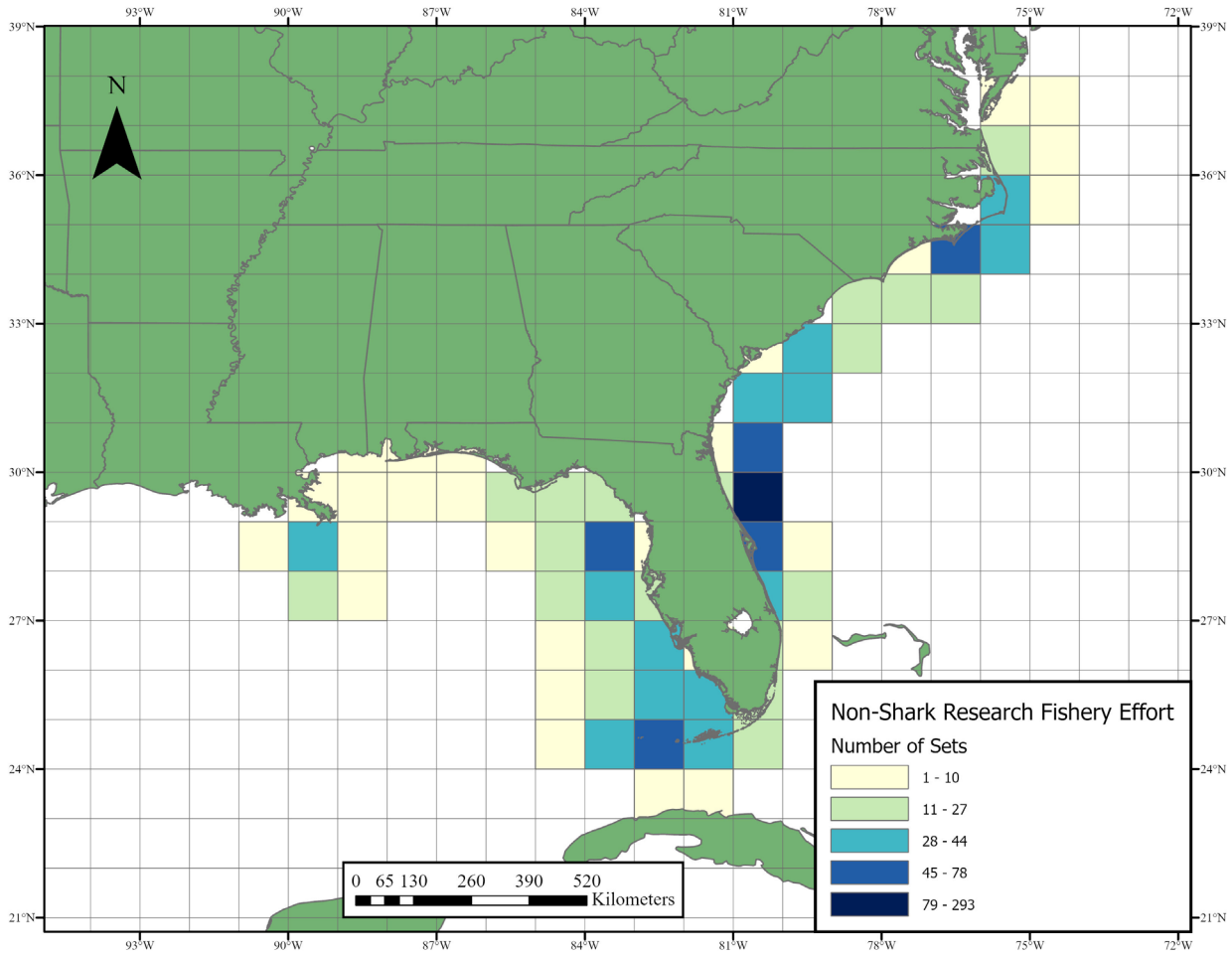
After selecting the set of fixed factors and interactions for each error distribution, all interactions that included the factor year were treated as random interactions (Ortiz and Arocha, 2004). This process converted the basic models from generalized linear models into generalized linear mixed models. The final model determination was evaluated using the Akaike Information Criteria (AIC). 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.

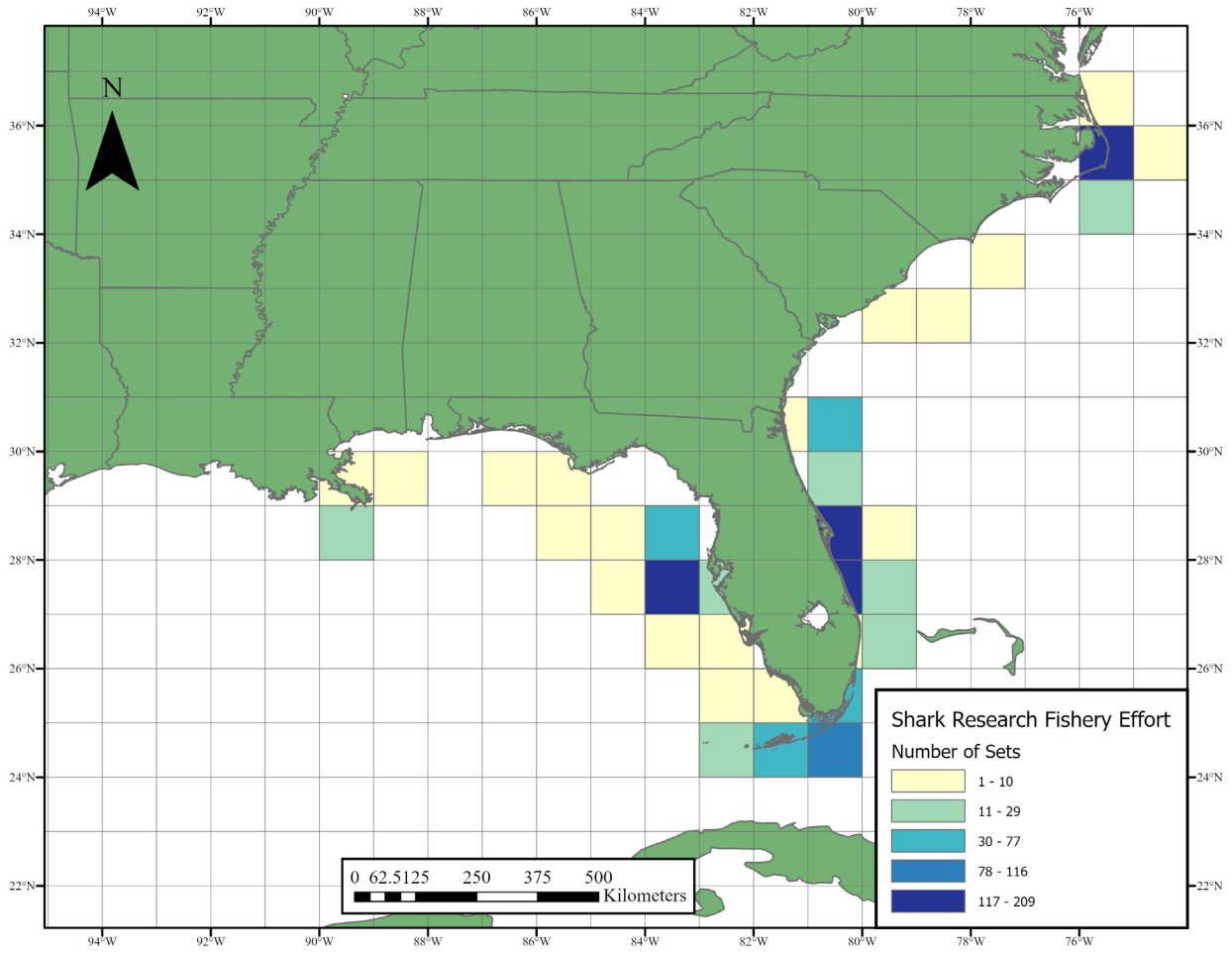
Results and Discussion

Figure 1. Distribution of fishing effort in the a) non-shark research fishery 1994-2007 and b) shark research fishery 2008-2019.

a)



b)



Great hammerhead

The proportion of positive sets (i.e. at least one shark was caught) was 19.4% for the non-research fishery and 33.6% for the research fishery. The stepwise construction of the models is summarized in Table 1. The index statistics 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 mean 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 binomial and lognormal generalized linear formulations of the proportion of positive and positive catches for great hammerhead for all areas.

Non-Research Fishery

Proportion positive-Binomial error distribution					
FACTOR	**DEVIANCE/DF**	**%DIFF**	**DELTA%**	**CHISQUARE**	**PR>CHI**
NULL	0.9939				
YEAR	0.9829	1.107	1.107	28.81	0.007

YEAR+					
TIME	0.9492	4.497	3.391	49.78	<.0001
AREA	0.9613	3.280		32.3	<.0001
DEPTH	0.967	2.707		25.96	<.0001
SEASON	0.9802	1.378		6.84	0.0772
SOAK	0.9807	1.328		4.27	0.0387
HOOKTYPE	0.9819	1.207		3.4	0.183
BAIT	0.9838	1.016		0.73	0.6947
YEAR+TIME+					
DEPTH	0.932	6.228	1.731	27.62	<.0001
AREA	1.0328	*		22.43	<.0001
PROPORTION POSITIVE	**AIC**				
YEAR+TIME+DEPTH	276.8				
YEAR*TIME	277.6				
YEAR*DEPTH	276.8				

Proportion positive-Lognormal error distribution					
FACTOR	**DEVIANCE/DF**	**%DIFF**	**DELTA%**	**CHISQUARE**	**PR>CHI**
NULL	0.5288				
YEAR	0.4955	6.297	6.297	32.66	0.0019
YEAR+					
HOOKTYPE	0.4854	8.207	1.910	8.16	0.0169
AREA	0.4864	8.018		6.53	0.0106
SEASON	0.4864	8.018		8.64	0.0345
BAIT	0.4928	6.808		3.72	0.1554
DEPTH	0.4939	6.600		4.08	0.2529
TIME	0.4965	6.108		0.45	0.5015
SOAK	0.4972	5.976		0.02	0.876
YEAR+HOOKTYPE+					
SEASON	0.4783	9.550	1.343	7.61	0.0548
AREA	0.4818	8.888		3.29	0.0698
POSITIVE	**AIC**				
YEAR+HOOKTYPE	643.4				
YEAR*HOOKTYPE	643.9				

Research Fishery

Proportion positive-Binomial error distribution					
FACTOR	**DEVIANCE/DF**	**%DIFF**	**DELTA%**	**CHISQUARE**	**PR>CHI**
NULL	1.3474				
YEAR	1.3142	2.464	2.464	55.12	<.0001
YEAR+					
BAIT	1.2618	6.353	3.889	66.18	<.0001
REGION	1.2668	5.982		58.87	<.0001
TIME	1.2669	5.974		58.77	<.0001
DEPTH	1.2923	4.089		30.48	<.0001

HOOKTYPE	1.3101	2.768		6.26	0.0123
SEASON	1.3137	2.501		4.52	0.2103
SOAK	1.3149	2.412		0.44	0.5092
YEAR+BAIT+					
TIME	1.2333	8.468	2.115	35.77	<.0001
DEPTH	1.2409	7.904		29.15	<.0001
REGION	1.2472	7.437		18.99	<.0001
HOOKTYPE	1.2621	6.331		0.89	0.3445
YEAR+BAIT+TIME+					
DEPTH	1.2155	9.789	1.321	25.25	<.0001
REGION	1.2226	9.262		14.23	0.0002
PROPORTION POSITIVE	**AIC**				
YEAR+BAIT+TIME+DEPTH	301.9				
YEAR*BAIT	346.2				
YEAR*TIME	477.3				
YEAR*DEPTH	440.2				

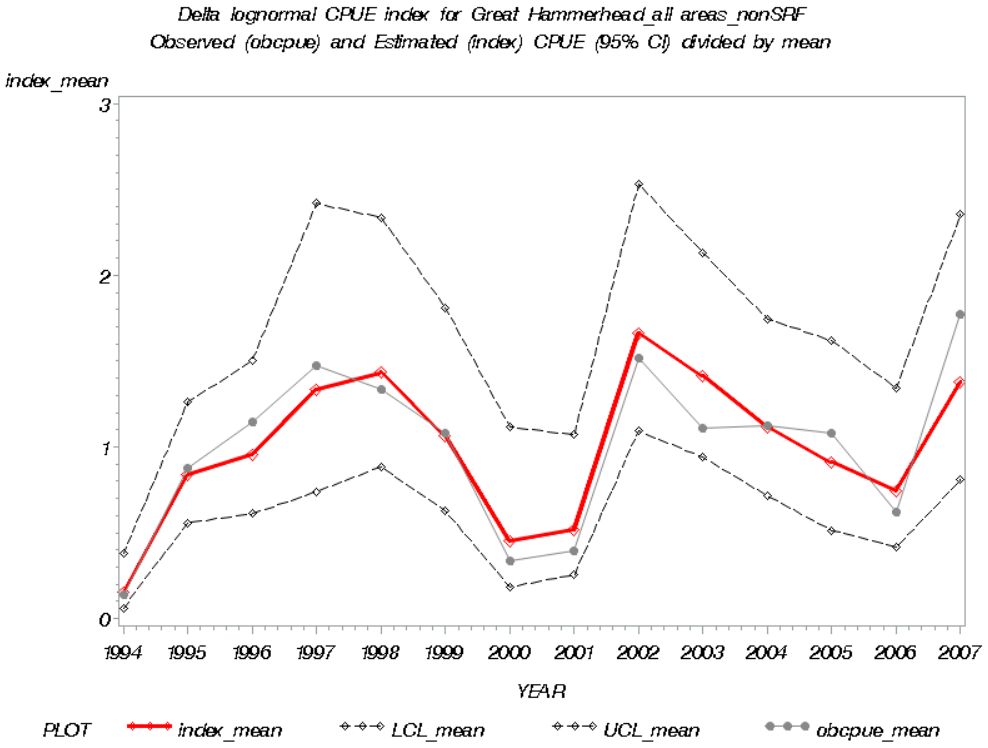
Proportion positive-Lognormal error distribution					
FACTOR	**DEVIANCE/DF**	**%DIFF**	**DELTA%**	**CHISQUARE**	**PR>CHI**
NULL	0.61				
YEAR	0.5821	4.574	4.574	33.28	0.0005
YEAR+					
SEASON	0.5672	7.016	15.41	0.0015	
BAIT	0.5755	5.656		7.45	0.0241
DEPTH	0.5795	5.000		0.1215	
SOAK	0.5799	4.934		0.0913	
TIME	0.58	4.918		0.094	
HOOKTYPE	0.5831	4.410		0.5945	
REGION	0.5831	4.410		0.6338	
YEAR+SEASON+					
BAIT	0.5635	7.623		5.16	0.0758
POSITIVE	**AIC**				
YEAR+SEASON	1099.4				
YEAR*SEASON	1099.4				

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

Year	Nominal	StdErr	N	Standardized index	LCL	UCL	CV
1994	0.960	0.513	102	1.071	0.432	2.656	0.478
1995	5.890	1.215	162	5.908	3.932	8.877	0.206
1996	7.720	1.542	126	6.749	4.298	10.598	0.229
1997	9.916	2.854	80	9.424	5.212	17.042	0.303

1998	8.975	2.495	110	10.140	6.244	16.468	0.246
1999	7.276	2.030	99	7.511	4.417	12.774	0.270
2000	2.261	1.517	64	3.207	1.306	7.878	0.473
2001	2.673	1.363	77	3.674	1.792	7.535	0.371
2002	10.194	2.491	132	11.726	7.704	17.848	0.212
2003	7.466	2.061	174	9.966	6.619	15.006	0.207
2004	7.549	1.782	122	7.873	5.035	12.310	0.226
2005	7.259	1.884	114	6.425	3.618	11.411	0.293
2006	4.159	1.577	117	5.261	2.926	9.460	0.300
2007	11.932	2.646	63	9.718	5.693	16.590	0.272
2008	33.374	9.116	62	40.370	25.843	63.062	0.226
2009	35.463	7.115	113	29.215	18.077	47.216	0.244
2010	17.891	4.003	185	18.072	11.666	27.996	0.221
2011	33.878	5.078	252	26.748	18.360	38.969	0.190
2012	45.942	13.290	88	43.110	23.598	78.756	0.308
2013	58.537	10.434	98	52.307	35.236	77.649	0.199
2014	32.922	8.750	106	40.176	26.120	61.795	0.218
2015	55.824	9.964	100	57.252	40.527	80.877	0.174
2016	22.077	7.744	81	26.352	14.820	46.858	0.294
2017	42.070	9.061	117	47.025	32.099	68.891	0.193
2018	23.842	6.695	112	26.739	16.329	43.785	0.250
2019	35.852	9.554	100	43.489	28.172	67.136	0.220

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



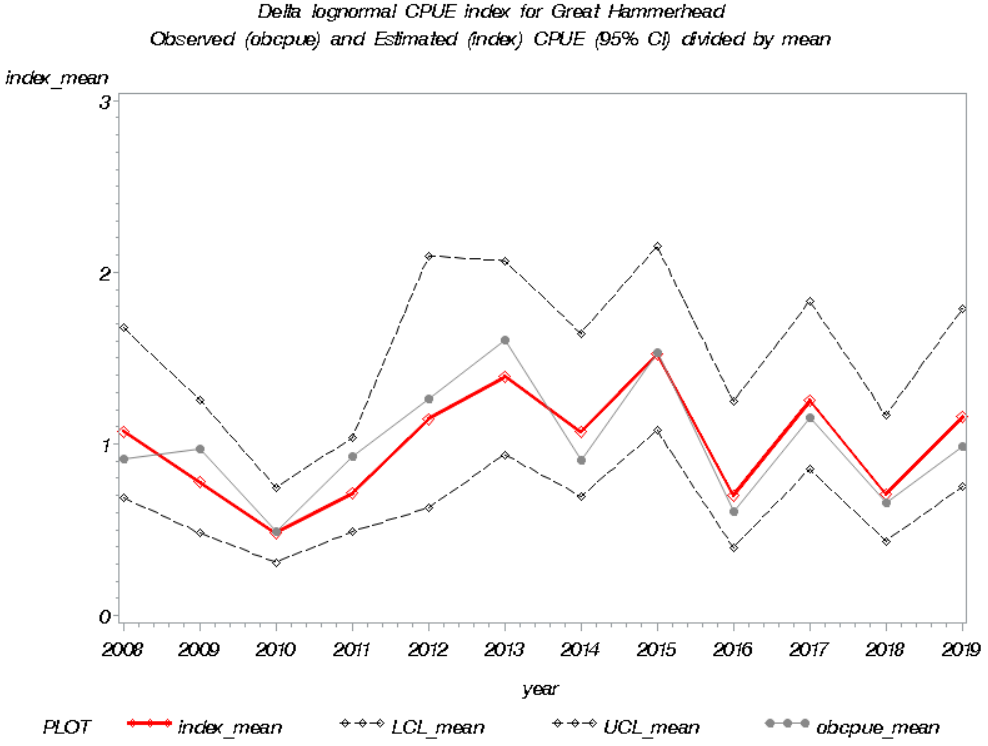
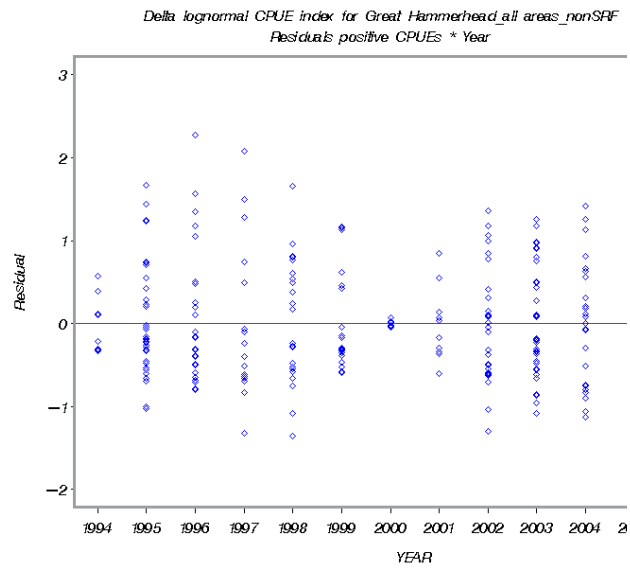
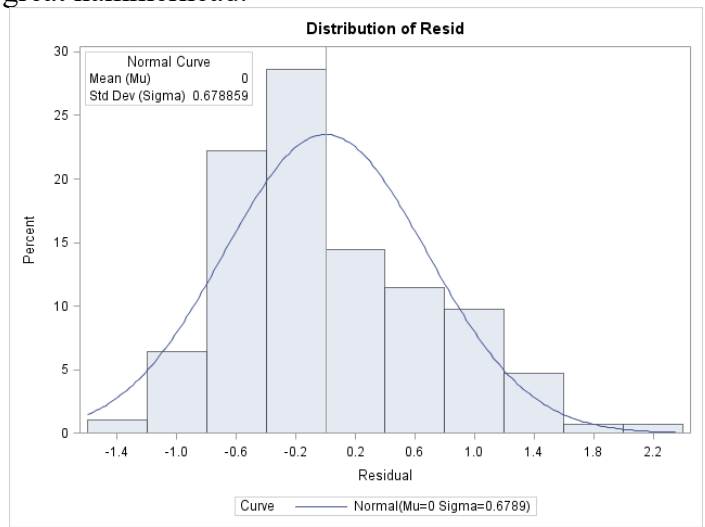
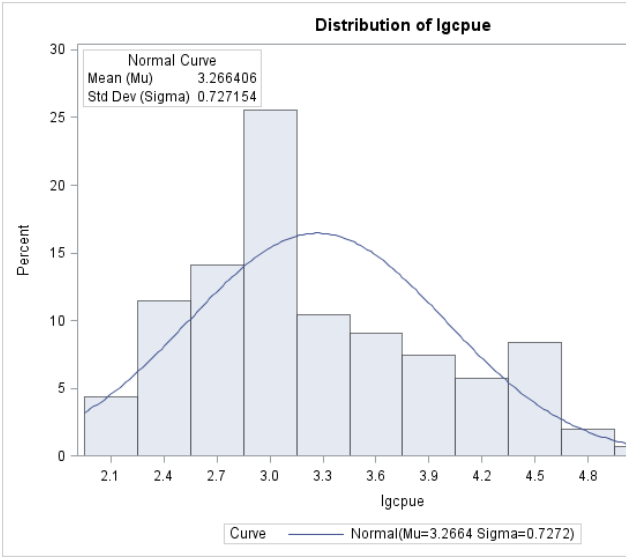
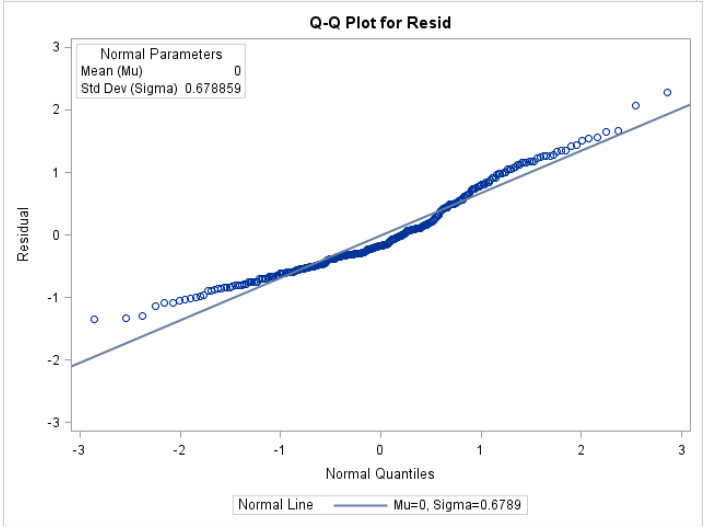


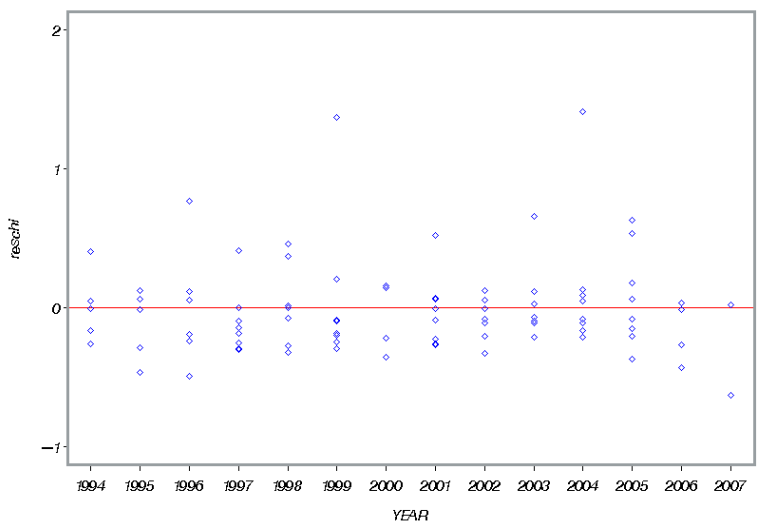
Figure 3. Diagnostic plots of the model outputs for great hammerhead.











Scalloped hammerhead

All Areas

The proportion of positive sets (i.e. at least one shark was caught) was 22.1% for the non-research fishery and 32.9% for the research fishery. The stepwise construction of the models is summarized in Table 3. The index statistics can be found in Table 4. The delta-lognormal abundance index is shown in Figure 4. To allow for visual comparison with the nominal values, both series were scaled to the mean of their respective index. Diagnostic plots assessing the fit of the models were deemed acceptable (Figure 5).

Table 3. Analysis of deviance of explanatory variables for the binomial and lognormal generalized linear formulations of the proportion of positive and positive catches for scalloped hammerhead for all areas.

Non-Research Fishery-All Areas

Proportion positive-Binomial error distribution					
FACTOR	**DEVIANCE/DF**	**%DIFF**	**DELTA%**	**CHISQUARE**	**PR>CHI**
NULL	1.0793				
YEAR	0.9969	7.635	7.635	133.17	<.0001
YEAR+					
DEPTH	0.9422	12.703	5.068	82.01	<.0001
BAIT	0.9903	8.246		11.55	0.0031
SOAK	0.9909	8.190		9.76	0.0018
SEASON	0.9918	8.107		10.4	0.0154
TIME	0.9942	7.885		4.92	0.0265
HOOKTYPE	0.9972	7.607		1.57	0.4557
AREA	0.9975	7.579		0.16	0.6847
YEAR+DEPTH					
BAIT	0.931	13.740	1.038	17.98	0.0001
TIME	0.9379	13.101		7.07	0.0078
SOAK	0.9393	12.971		5.02	0.0251
SEASON	0.94	12.907		5.95	0.1139
PROPORTION POSITIVE	**AIC**				
YEAR+DEPTH+BAIT	**357.9**				
YEAR*DEPTH	360.1				
YEAR*BAIT	358				
Proportion positive-Lognormal error distribution					
FACTOR	**DEVIANCE/DF**	**%DIFF**	**DELTA%**	**CHISQUARE**	**PR>CHI**
NULL	1.0817				
YEAR	1.0153	6.138	6.138	34.8	0.0009
YEAR+					
DEPTH	0.9195	14.995	8.856	36.74	<.0001
SEASON	0.9843	9.004		13.64	0.0034
TIME	1.0011	7.451		5.81	0.0159

BAIT	1.0087	6.749		4.3	0.1163
SOAK	1.0147	6.194		1.22	0.2696
HOOKTYPE	1.0215	5.565		0.01	0.9928
AREA	0.9918	8.311		8.96	0.0028
YEAR+DEPTH					
SEASON	0.8895	17.768	2.773	14.43	0.0024
TIME	0.8924	17.500		11.21	0.0008
YEAR+DEPTH+SEASON+					
TIME	0.8612	20.385	2.616	12.02	0.0005
POSITIVE	**AIC**				
YEAR+DEPTH+SEASON+TIME	922.7				
YEAR*DEPTH	923.9				
YEAR*SEASON	**917.3**				
YEAR*TIME	922.7				

Research Fishery-All Areas

Proportion positive-Binomial error distribution					
FACTOR	**DEVIANCE/DF**	**%DIFF**	**DELTA%**	**CHISQUARE**	**PR>CHI**
NULL	1.3124				
YEAR	1.2705	3.193	3.193	65.45	<.0001
YEAR+					
DEPTH	1.1484	12.496	9.304	151.79	<.0001
BAIT	1.1752	10.454		118.14	<.0001
SEASON	1.2366	5.776		44.85	<.0001
SOAK	1.2699	3.238		1.96	0.1614
HOOKTYPE	1.2707	3.177		1.03	0.3103
TIME	1.2711	3.147		0.53	0.4645
YEAR+DEPTH+					
BAIT	1.0899	16.954	4.457	73.05	<.0001
SEASON	1.127	14.127		29.32	<.0001
YEAR+DEPTH+BAIT+					
SEASON	1.0675	18.660	1.707	30.28	<.0001
PROPORTION POSITIVE	**AIC**				
YEAR+DEPTH+BAIT+SEASON	524.4				
YEAR*SEASON	525.7				
YEAR*BAIT	526.3				
YEAR*DEPTH	528.1				

Proportion positive-Lognormal error distribution					
FACTOR	**DEVIANCE/DF**	**%DIFF**	**DELTA%**	**CHISQUARE**	**PR>CHI**
NULL	1.119				
YEAR	1.0835	3.172	3.172	26.08	0.0063
YEAR+					

DEPTH	0.9693	13.378	10.206	54.8	<.0001
TIME	1.0491	6.247		16.01	<.0001
SEASON	1.0685	4.513		9.57	0.0226
BAIT	1.0727	4.138		6.73	0.0346
HOOKTYPE	1.0821	3.298		1.64	0.1997
SOAK	1.0859	2.958		0.01	0.9102
YEAR+DEPTH+					
SEASON	0.9514	14.978	1.600	11.75	0.0083
TIME	0.9554	14.620		7.71	0.0055
BAIT	0.9693	13.378		2.07	0.3557
POSITIVE	**AIC**				
YEAR*DEPTH	1298.9				
YEAR+DEPTH+SEASON	1309.7				
YEAR*SEASON	1309.8				

Table 4. The absolute standardized and nominal index of abundance for scalloped hammerhead- all areas with the associated coefficients of variation (CV) and number of sets observed (N).

Year	Nominal	StdErr	N	Standardized index	LCL	UCL	CV
1994	2.964	2.525	102	5.867	2.573	13.382	0.430
1995	4.271	3.763	162	8.990	4.025	20.082	0.419
1996	5.941	3.596	126	9.030	4.193	19.451	0.398
1997	19.310	4.532	80	9.015	3.489	23.295	0.503
1998	15.680	5.784	110	12.811	5.413	30.318	0.452
1999	2.738	2.332	99	3.266	0.905	11.792	0.714
2000	0.319	0.449	64	0.281	0.030	2.671	1.596
2001	20.443	5.420	77	12.125	5.164	28.469	0.447
2002	25.727	6.425	132	16.468	7.756	34.963	0.390
2003	36.856	6.956	174	20.271	10.401	39.506	0.343
2004	26.529	6.254	122	16.563	7.981	34.375	0.378
2005	42.121	3.554	114	6.975	2.669	18.231	0.509
2006	16.997	10.221	117	25.205	11.551	55.003	0.405
2007	9.366	8.727	63	15.530	5.447	44.277	0.562
2008	15.784	3.192	62	4.129	1.050	16.232	0.773
2009	239.310	21.716	113	65.590	34.412	125.017	0.331
2010	52.831	15.379	185	46.926	24.773	88.890	0.328
2011	69.029	19.029	252	58.507	31.030	110.317	0.325
2012	69.764	33.856	88	90.500	43.882	186.642	0.374
2013	52.240	20.983	98	53.035	24.735	113.710	0.396
2014	79.902	24.385	106	68.047	33.955	136.369	0.358

2015	66.895	37.107	100	99.944	48.710	205.064	0.371
2016	59.258	24.662	81	68.444	34.030	137.660	0.360
2017	79.150	32.465	117	89.840	44.583	181.038	0.361
2018	26.229	16.842	112	42.589	19.871	91.283	0.395
2019	29.696	17.176	100	44.341	20.991	93.666	0.387

Figure 4. Nominal and standardized indices of abundance for scalloped hammerhead-all areas. The dashed lines are the 95% confidence limits for the standardized index. Each index has been divided by the mean of the index.

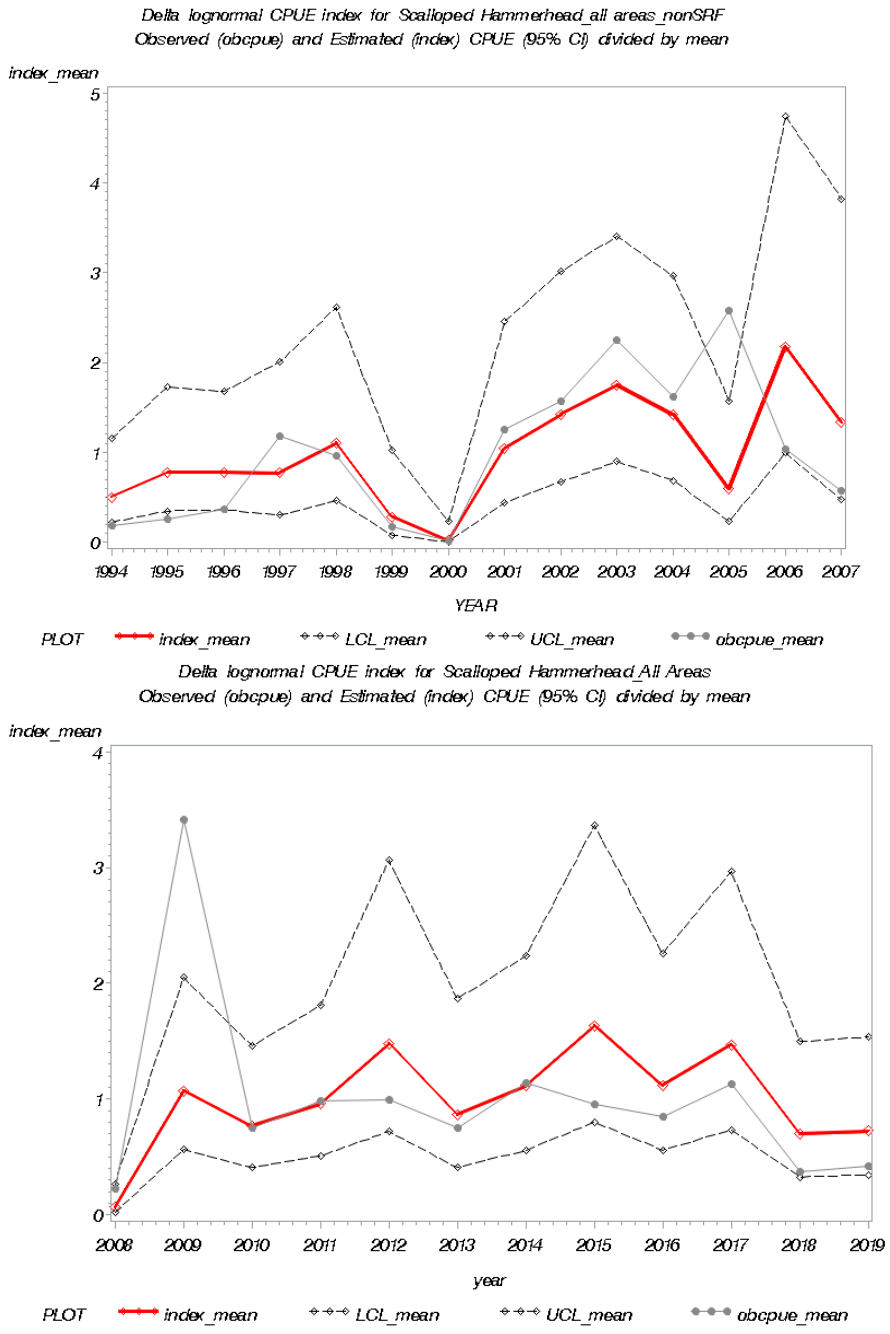
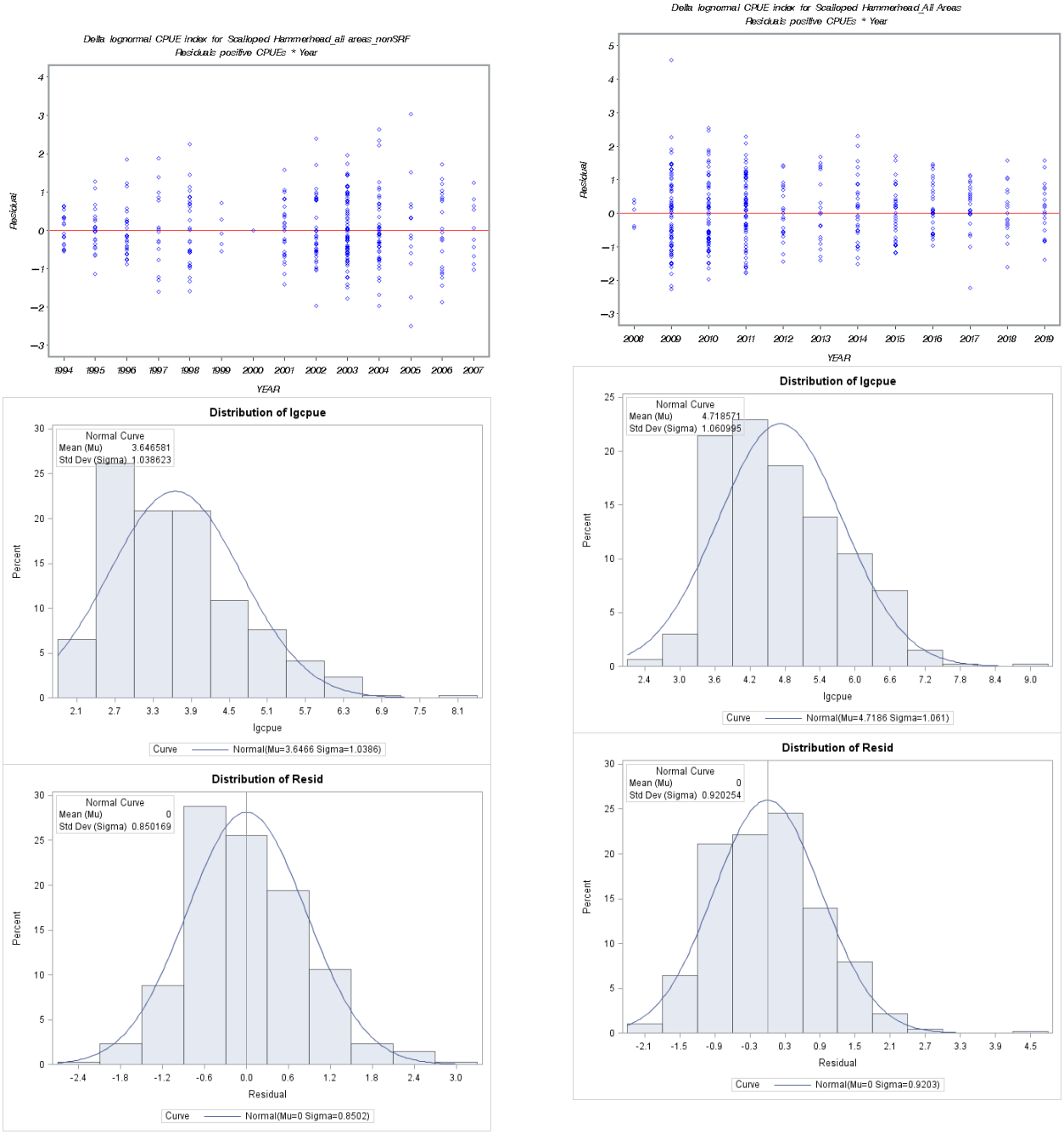
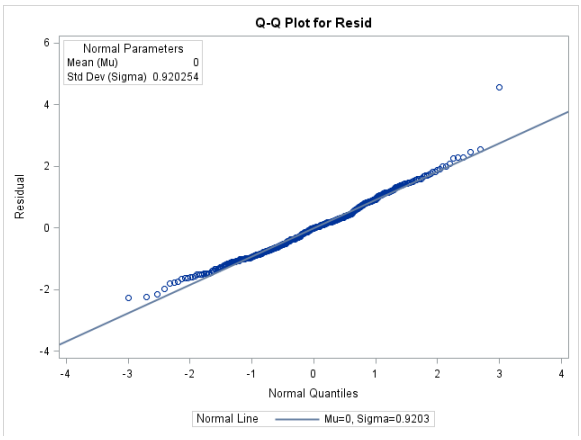
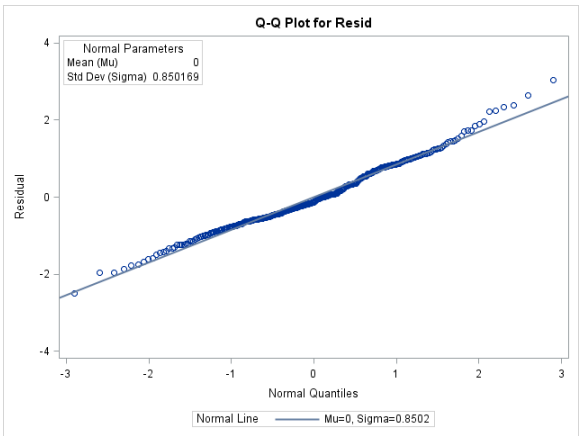
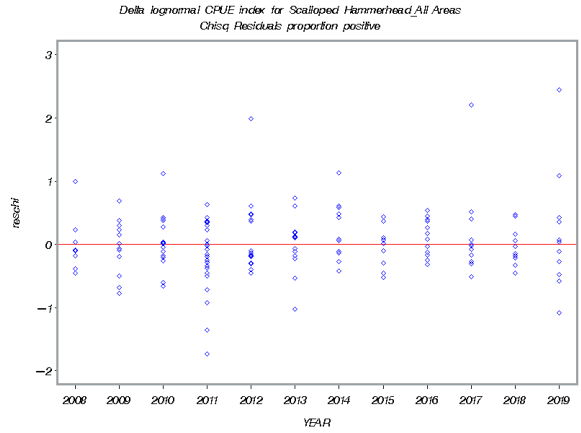


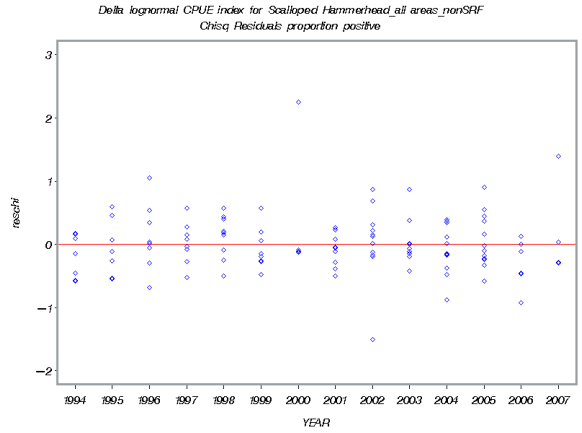
Figure 5. Diagnostic plots of the model outputs for scalloped hammerhead-all areas.











Scalloped hammerhead

Atlantic Ocean

The proportion of positive sets (i.e. at least one shark was caught) was 20.0% for the non-research fishery and 26.9% for the research fishery. The stepwise construction of the models is summarized in Table 5. The index statistics can be found in Table 6. The delta-lognormal abundance index is shown in Figure 6. To allow for visual comparison with the nominal values, both series were scaled to the mean of their respective index. Diagnostic plots assessing the fit of the models were deemed acceptable (Figure 7).

Table 5. Analysis of deviance of explanatory variables for the binomial and lognormal generalized linear formulations of the proportion of positive and positive catches for scalloped hammerhead for the Atlantic Ocean. An asterisk indicates the model did not converge.

Non-Research Fishery-Atlantic Ocean

Proportion positive-Binomial error distribution					
FACTOR	**DEVIANCE/DF**	**%DIFF**	**DELTA%**	**CHISQUARE**	**PR>CHI**
NULL	1.0213				
YEAR	0.9694	5.082	5.082	57.2	<.0001

YEAR+					
DEPTH	0.9265	9.282	4.201	39.13	<.0001
BAIT	0.9534	6.648		15.5	0.0004
SEASON	0.9601	5.992		10.74	0.0132
HOOKTYPE	0.9633	5.679		7.11	0.0285
TIME	0.967	5.317		3.02	0.0823
SOAK	0.9682	5.199		2.03	0.1546
YEAR+DEPTH+					
BAIT	0.9046	11.427	2.144	20.22	<.0001
SEASON	0.9204	9.880		7.87	0.0489
HOOKTYPE	0.9207	9.850		6.68	0.0354
YEAR+DEPTH+BAIT+					
SEASON	0.8973	12.141	0.715	8.82	0.0318
PROPORTION POSITIVE	**AIC**				
YEAR+DEPTH+BAIT	344.5				
YEAR*DEPTH	346.2				
YEAR*BAIT	343.4				

Proportion positive-Lognormal error distribution					
FACTOR	**DEVIANCE/DF**	**%DIFF**	**DELTA%**	**CHISQUARE**	**PR>CHI**
NULL	1.1853				
YEAR	0.9305	21.497	21.497	57.86	<.0001
YEAR+					
DEPTH	0.7872	33.586	12.090	33.88	<.0001
SEASON	0.8984	24.205		9.69	0.0214
TIME	0.9128	22.990		4.58	0.0323
BAIT	0.9182	22.534		4.6	0.1004
SOAK	0.9283	21.682		1.51	0.2185
HOOKTYPE	0.9375	20.906		0.8	0.6711
YEAR+DEPTH+					
TIME	0.7378	37.754	4.168	12.97	0.0003
SEASON	0.7728	34.801		6.71	0.0817
POSITIVE	**AIC**				
YEAR+DEPTH+TIME	468.7				
YEAR*DEPTH	468.7				
YEAR*TIME	470.7				

Research Fishery-Atlantic Ocean

Proportion positive-Binomial error distribution					
FACTOR	**DEVIANCE/DF**	**%DIFF**	**DELTA%**	**CHISQUARE**	**PR>CHI**
NULL	1.2097				
YEAR	1.186	1.959	1.959	29.93	0.0016
YEAR+					

BAIT	1.0735	11.259	9.300	80.96	<.0001
HOOKTYPE	1.1413	5.654		32.43	<.0001
SEASON	1.1453	5.324		31.95	<.0001
DEPTH	1.153	4.687		Negative of Hessian not positive definite	
SOAK	1.1856	1.992		1.44	0.23
TIME	1.1863	1.934		0.96	0.3279
YEAR+BAIT+					
SEASON	1.0393	14.086	2.827	27.07	<.0001
HOOKTYPE	1.062	12.210		9.1	0.0026
YEAR+BAIT+SEASON+					
HOOKTYPE	1.0267	15.128	1.042	11.75	0.0083
PROPORTION POSITIVE	AIC				
YEAR+BAIT+SEASON+HOOKTYPE	333.5				
YEAR*BAIT	*				
YEAR*SEASON	*				
YEAR*HOOKTYPE	*				

Proportion positive-Lognormal error distribution					
FACTOR	**DEVIANCE/DF**	**%DIFF**	**DELTA%**	**CHISQUARE**	**PR>CHI**
NULL	1.119				
YEAR	1.0835	3.172	3.172	26.08	0.0063
YEAR+					
DEPTH	0.9693	13.378	10.206	54.8	<.0001
TIME	1.0491	6.247		16.01	<.0001
SEASON	1.0685	4.513		9.57	0.0226
BAIT	1.0727	4.138		6.73	0.0346
HOOKTYPE	1.0821	3.298		1.64	0.1997
SOAK	1.0859	2.958		0.01	0.9102
YEAR+DEPTH+					
SEASON	0.9514	14.978	1.600	11.75	0.0083
TIME	0.9554	14.620		7.71	0.0055
BAIT	0.9693	13.378		2.07	0.3557
POSITIVE	AIC				
YEAR+DEPTH+SEASON	590.6				
YEAR*DEPTH	*				
YEAR*SEASON	*				

Table 6. The absolute standardized and nominal index of abundance for scalloped hammerhead-Atlantic Ocean with the associated coefficients of variation (CV) and number of sets observed (N).

Year	Nominal	StdErr	N	Standardized index	LCL	UCL	CV
1994	5.128	3.331	55	9.514	4.819	18.780	0.350
1995	4.599	4.200	109	11.957	6.044	23.653	0.351

1996	5.505	4.200	86	12.727	6.691	24.209	0.330
1997	5.467	3.357	54	6.067	2.158	17.054	0.553
1998	14.332	5.422	72	17.577	9.617	32.124	0.308
1999	3.477	4.409	68	5.929	1.573	22.350	0.744
2000	0.319	0.340	64	0.229	0.027	1.983	1.482
2001	15.166	6.366	54	16.904	8.160	35.019	0.377
2002	37.115	6.385	68	17.461	8.597	35.464	0.366
2003	46.451	4.265	93	12.811	6.698	24.502	0.333
2004	13.098	3.313	52	7.867	3.506	17.650	0.421
2005	94.693	7.831	48	11.620	3.418	39.507	0.674
2006	34.397	23.685	49	63.093	30.521	130.425	0.375
2007	8.300	12.759	35	21.511	7.174	64.500	0.593
2008	0.000		21				
2009	88.457	27.083	40	63.443	27.990	143.802	0.427
2010	46.727	11.902	127	46.747	28.318	77.168	0.255
2011	56.688	10.135	144	37.435	21.992	63.721	0.271
2012	67.320	27.841	60	91.472	50.437	165.890	0.304
2013	57.714	28.282	51	64.498	27.880	149.210	0.438
2014	70.030	15.420	90	53.727	30.607	94.310	0.287
2015	56.095	22.083	61	63.541	32.340	124.841	0.348
2016	50.635	17.886	52	56.871	30.771	105.112	0.315
2017	21.505	14.914	62	40.475	19.828	82.622	0.368
2018	38.249	15.429	59	41.877	20.516	85.482	0.368
2019	10.515	11.535	51	22.889	8.839	59.270	0.504

Figure 6. Nominal and standardized indices of abundance for scalloped hammerhead-Atlantic Ocean. The dashed lines are the 95% confidence limits for the standardized index. Each index has been divided by the mean of the index.

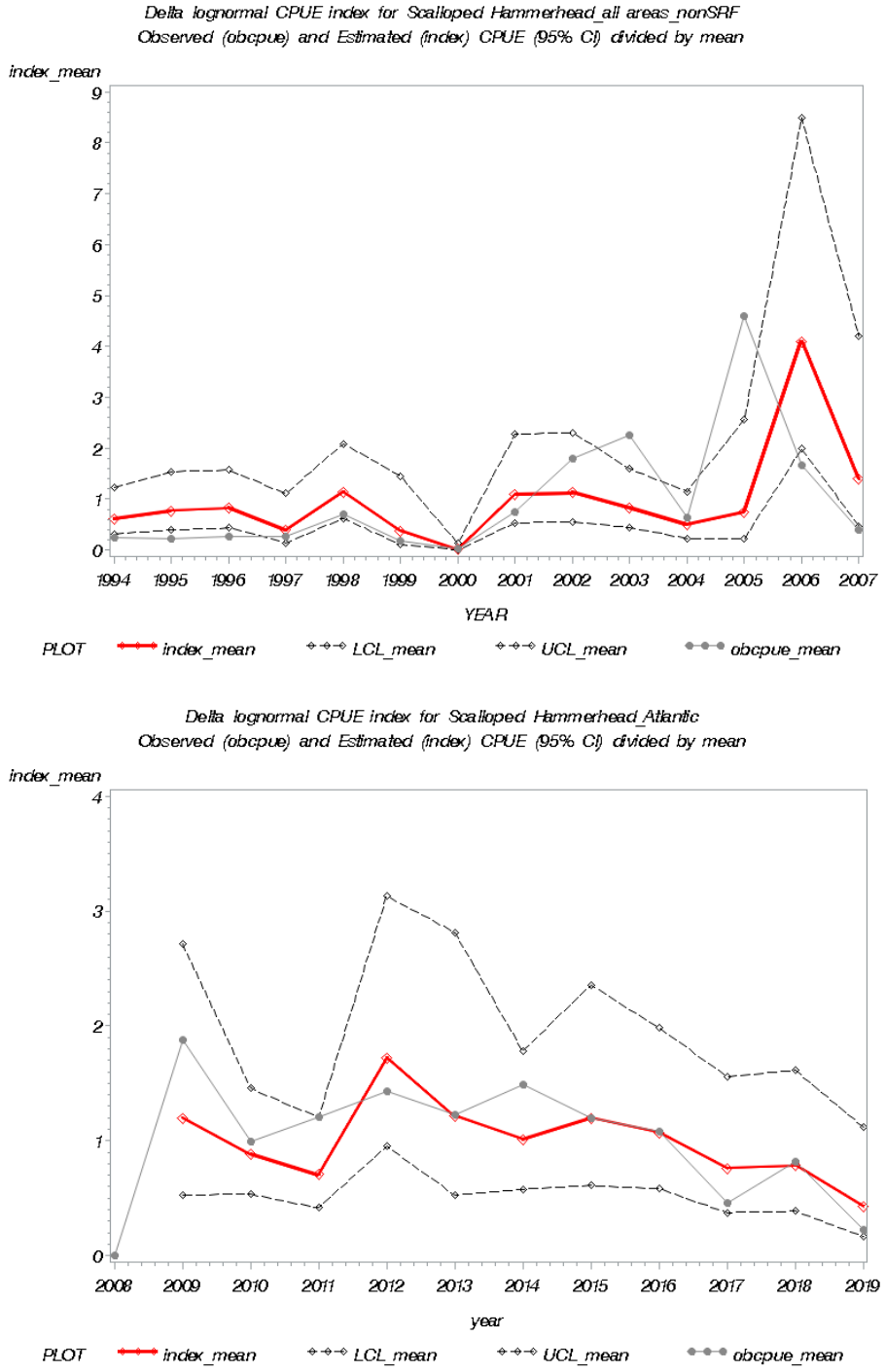
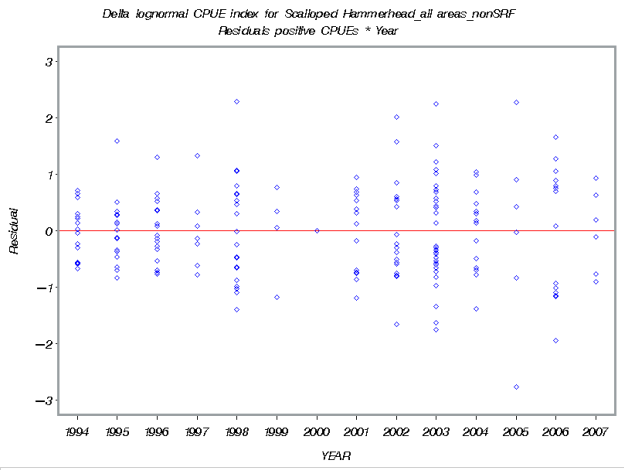
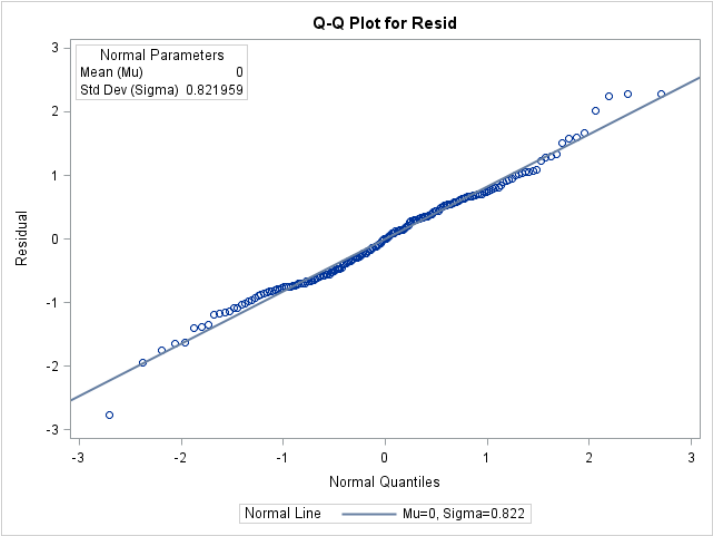
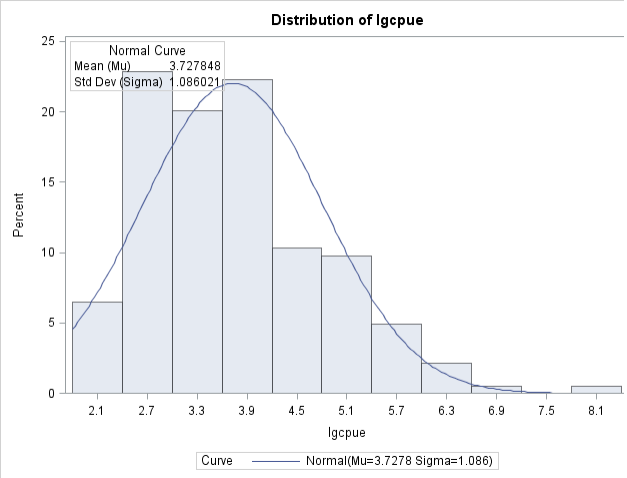
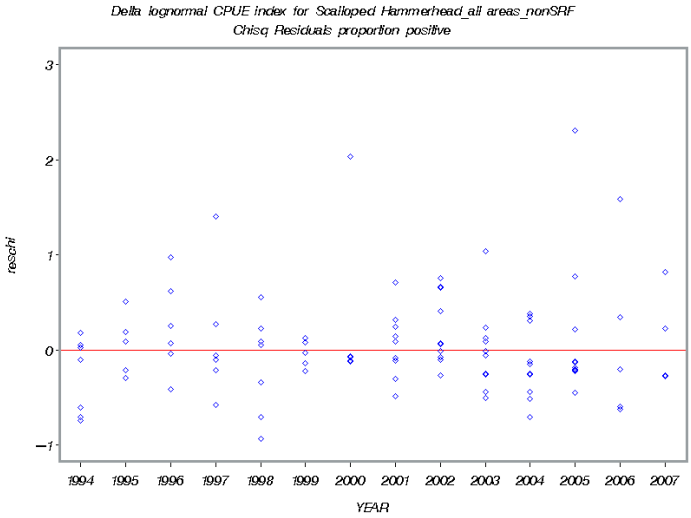


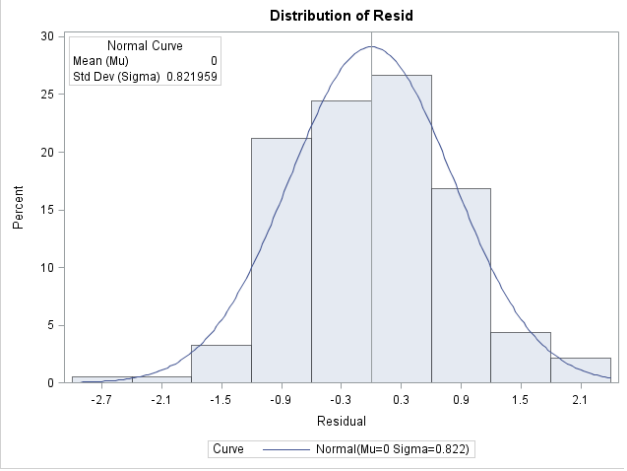
Figure 7. Diagnostic plots of the model outputs for scalloped hammerhead-Atlantic Ocean.

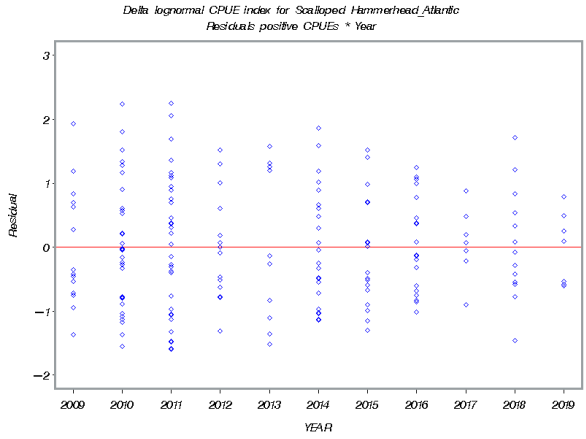


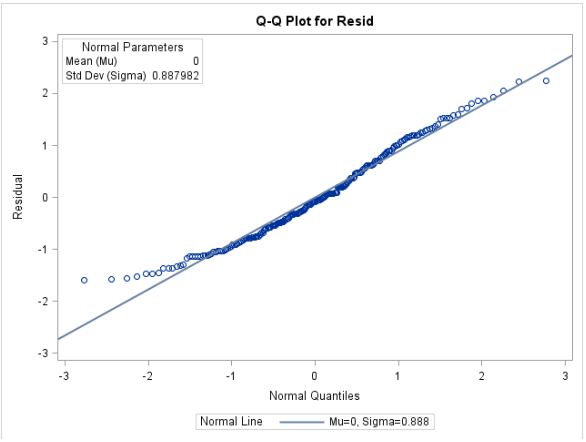


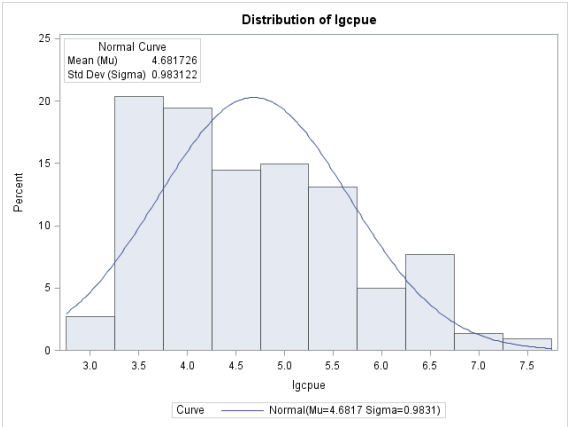


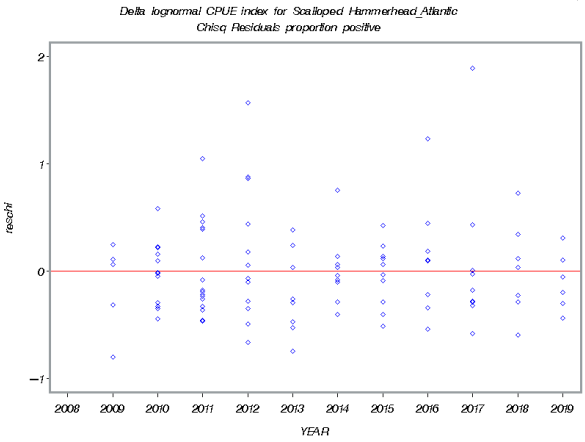


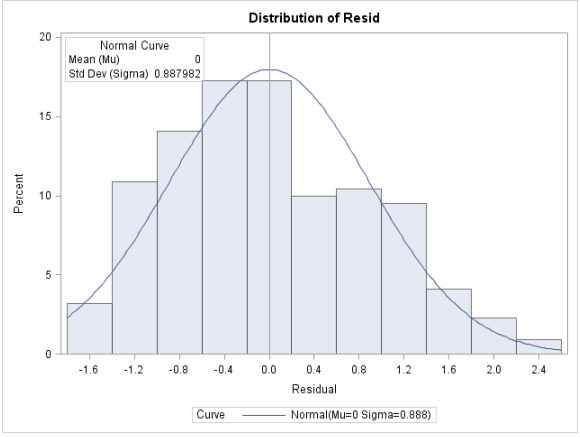












Scalloped hammerhead

Atlantic Ocean

The proportion of positive sets (i.e. at least one shark was caught) was 24.6% for the non-research fishery and 41.2% for the research fishery. The stepwise construction of the models is summarized in Table 7. The index statistics can be found in Table 8. The delta-lognormal abundance index is shown in Figure 8. To allow for visual comparison with the nominal values,

both series were scaled to the mean of their respective index. Diagnostic plots assessing the fit of the models were deemed acceptable (Figure 9).

Table 5. Analysis of deviance of explanatory variables for the binomial and lognormal generalized linear formulations of the proportion of positive and positive catches for scalloped hammerhead for the Gulf of Mexico. An asterisk indicates the model did not converge.

Non-Research Fishery- Gulf of Mexico

Proportion positive-Binomial error distribution					
FACTOR	**DEVIANCE/DF**	**%DIFF**	**DELTA%**	**CHISQUARE**	**PR>CHI**
NULL	1.158				
YEAR	0.9976	13.851	13.851	108.03	<.0001
YEAR+					
DEPTH	0.9013	22.168	8.316	59.22	<.0001
SOAK	0.9819	15.207		10.21	0.0014
HOOKTYPE	0.9881	14.672		7.57	0.0227
SEASON	0.9979	13.826		2.82	0.4197
TIME	0.9983	13.791		0.58	0.445
BAIT	1	13.644		0.63	0.7304
YEAR+DEPTH+					
HOOKTYPE	0.8921	22.962	0.794	7.19	0.0275
SOAK	0.897	22.539		3.43	0.064
PROPORTION POSITIVE	**AIC**				
YEAR+DEPTH	127				
YEAR*DEPTH	125.4				

Proportion positive-Lognormal error distribution					
FACTOR	**DEVIANCE/DF**	**%DIFF**	**DELTA%**	**CHISQUARE**	**PR>CHI**
NULL	0.9497				
YEAR	0.9478	0.200	0.200	12.88	0.3778
YEAR+					
DEPTH	0.9055	4.654	4.454	10.44	0.0152
SOAK	0.9357	1.474		3.11	0.0778
HOOKTYPE	0.9443	0.569		2.78	0.2496
TIME	0.9472	0.263		1.19	0.2744
SEASON	0.9502	*		2.92	0.4047
BAIT	0.9595	*		0.29	0.8641
POSITIVE	**AIC**				
YEAR+DEPTH	420.5				
YEAR*DEPTH	418.7				

Research Fishery- Gulf of Mexico

Proportion positive-Binomial error distribution					
FACTOR	**DEVIANCE/DF**	**%DIFF**	**DELTA%**	**CHISQUARE**	**PR>CHI**
NULL	1.396				
YEAR	1.3115	6.053	6.053	57.73	<.0001
YEAR+					
DEPTH	1.1422	18.181	12.128	88.42	<.0001
HOOKTYPE	1.2573	9.936		28.51	<.0001
SEASON	1.2617	9.620		28.81	<.0001
TIME	1.281	8.238		16.61	<.0001
SOAK	1.2864	7.851		13.89	0.0002
BAIT	1.2928	7.393		12.01	0.0025
YEAR+DEPTH+					
HOOKTYPE	1.0208	26.877	8.696	42.32	<.0001
SEASON	1.1091	20.552		19.88	0.0002
BAIT	1.1158	20.072		15.41	0.0005
SOAK	1.137	18.553		3.77	0.0522
TIME	1.1445	18.016		0.02	0.8795
No other models would converge					
PROPORTION POSITIVE	**AIC**				
YEAR+DEPTH+HOOKTYPE	90.4				
YEAR*DEPTH	92.3				
YEAR*HOOKTYPE	56.3				

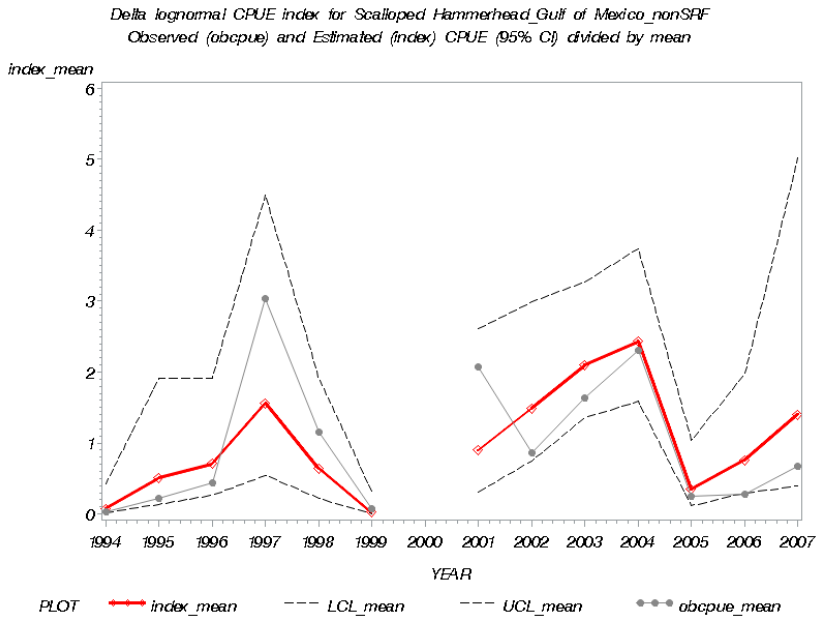
Proportion positive-Lognormal error distribution					
FACTOR	**DEVIANCE/DF**	**%DIFF**	**DELTA%**	**CHISQUARE**	**PR>CHI**
NULL	1.2715				
YEAR	1.2131	4.593	4.593	22.77	0.019
YEAR+					
HOOKTYPE	1.0251	19.379	14.786	42.15	<.0001
DEPTH	1.0388	18.301		39.97	<.0001
TIME	1.0709	15.777		31.48	<.0001
SEASON	1.1297	11.152		20.56	0.0001
SOAK	1.1885	6.528		6.05	0.0139
BAIT	1.2152	4.428		1.69	0.4296
YEAR+HOOKTYPE+					
DEPTH	0.9493	25.340	5.961	20.86	<.0001
TIME	0.9638	24.200		16.08	<.0001
SEASON	1.0015	21.235		8.87	0.0311
SOAK	1.0155	20.134		3.34	0.0675
YEAR+HOOKTYPE+DEPTH+					

TIME	0.9072	28.651	3.311	12.13	0.0005
SEASON	0.92	27.645		10.86	0.0125
YEAR+HOOKTYPE+DEPTH+TIME+					
SEASON	0.8657	31.915	3.264	14.65	0.0021
POSITIVE	**AIC**				
YEAR+HOOKTYPE+DEPTH+TIME+SEASON	663.4				
YEAR*HOOKTYPE	663.4				
YEAR*DEPTH	663.5				
YEAR*TIME	663.4				
YEAR*SEASON	664.9				

Table 8. The absolute standardized and nominal index of abundance for scalloped hammerhead-Gulf of Mexico with the associated coefficients of variation (CV) and number of sets observed (N).

Year	Nominal	StdErr	N	Standardized index	LCL	UCL	CV
1994	0.430	0.800	47	0.727	0.122	4.316	1.100
1995	3.599	3.560	53	4.445	1.088	18.169	0.801
1996	6.877	4.100	40	6.603	2.107	20.690	0.621
1997	48.062	14.879	26	23.542	7.384	75.055	0.632
1998	18.233	4.389	38	6.604	1.970	22.138	0.665
1999	1.116	0.603	31	0.399	0.045	3.533	1.511
2000			0				
2001	32.833	6.948	23	11.066	3.494	35.051	0.628
2002	13.628	6.686	64	14.561	6.071	34.921	0.459
2003	25.840	8.594	81	24.324	12.250	48.298	0.353
2004	36.506	8.348	70	24.302	12.461	47.396	0.344
2005	3.887	2.444	66	3.808	1.177	12.326	0.642
2006	4.458	5.406	68	6.982	1.773	27.496	0.774
2007	10.698	15.632	28	19.646	4.841	79.726	0.796
2008	23.869	9.832	41	11.196	2.468	50.787	0.878
2009	321.970	21.961	73	84.325	50.519	140.755	0.260
2010	66.198	13.967	58	41.180	21.284	79.671	0.339
2011	85.484	15.830	108	50.887	27.710	93.452	0.311
2012	75.000	34.925	28	64.255	23.227	177.754	0.544
2013	46.301	26.715	47	67.233	31.262	144.593	0.397
2014	135.431	34.376	16	61.826	21.896	174.575	0.556
2015	83.787	79.286	39	216.816	106.752	440.358	0.366
2016	74.720	35.487	29	78.541	33.169	185.980	0.452
2017	144.132	83.428	55	260.287	139.260	486.494	0.321
2018	12.849	14.702	53	31.181	12.727	76.396	0.472
2019	49.660	25.094	49	71.195	35.910	141.150	0.352

Figure 8. Nominal and standardized indices of abundance for scalloped hammerhead- Gulf of Mexico. The dashed lines are the 95% confidence limits for the standardized index. Each index has been divided by the mean of the index.



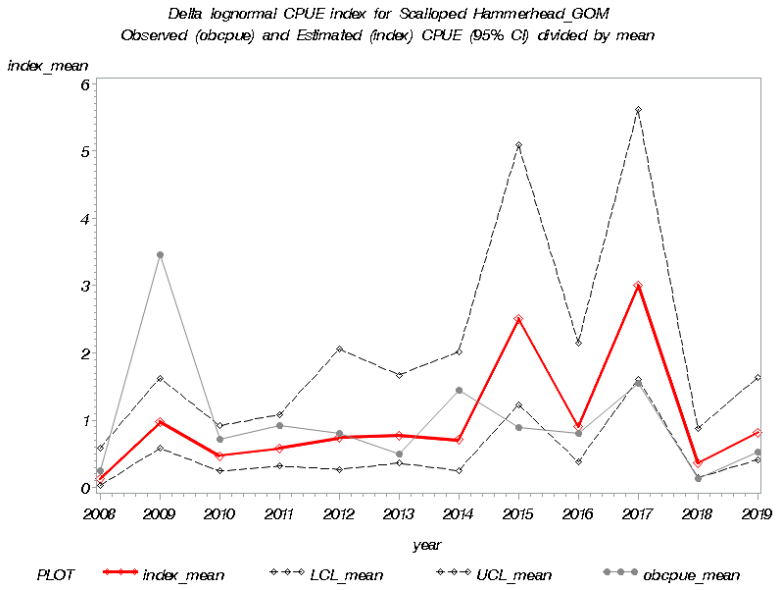
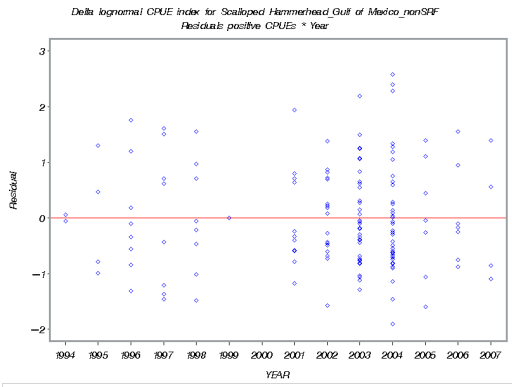
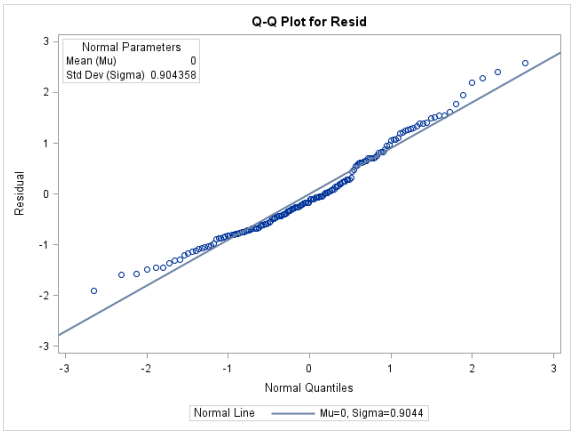
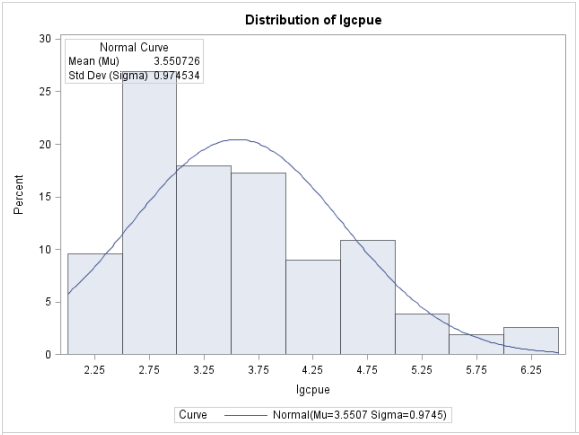
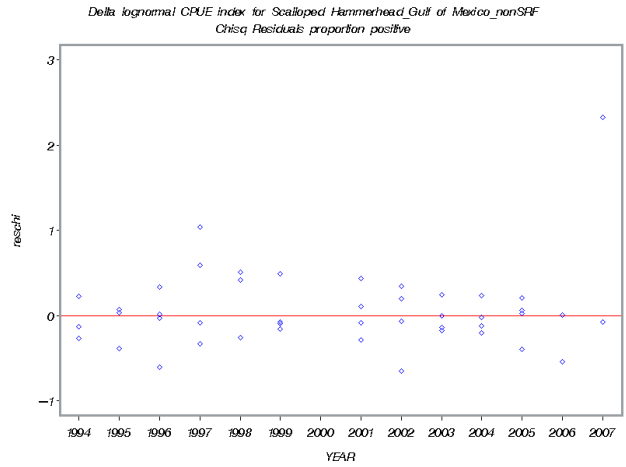


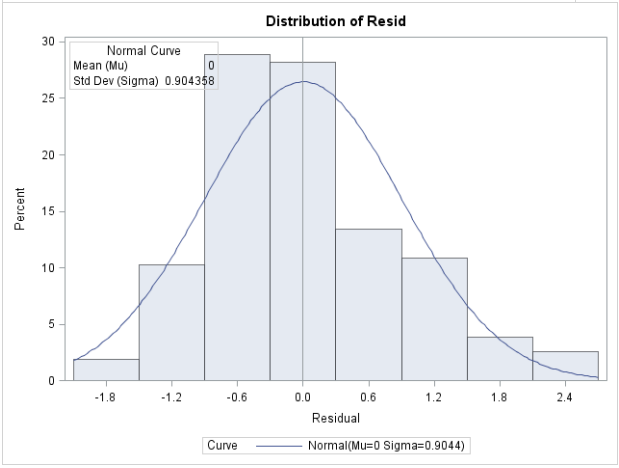
Figure 9. Diagnostic plots of the model outputs for scalloped hammerhead- Gulf of Mexico.

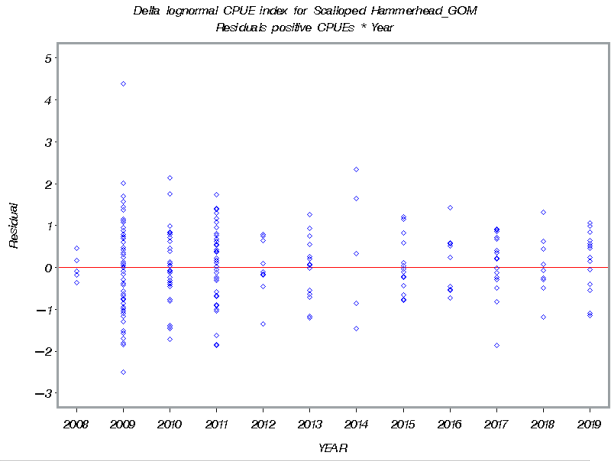


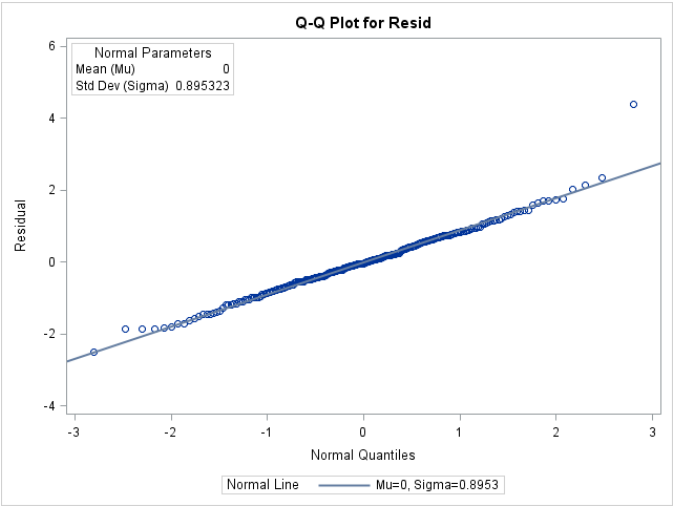


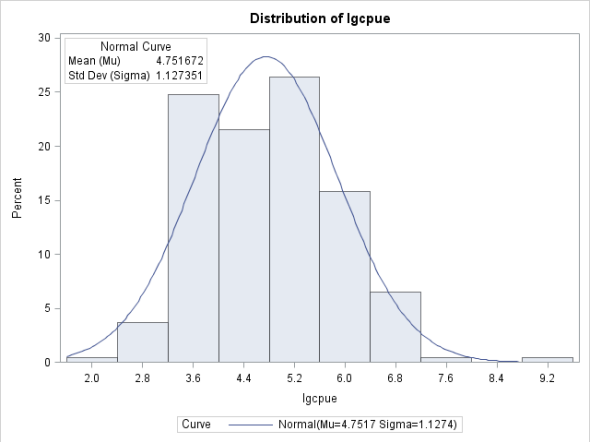


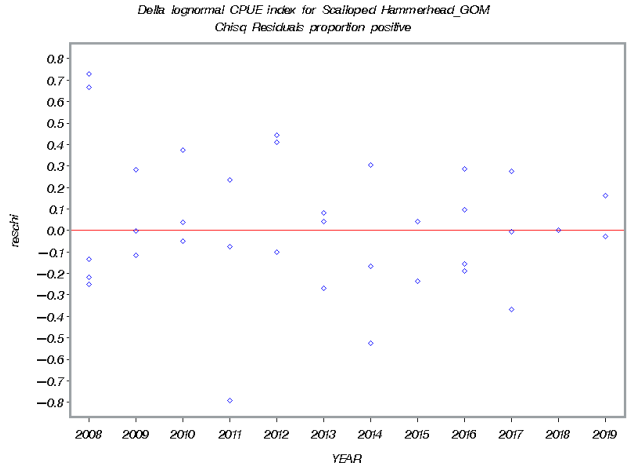


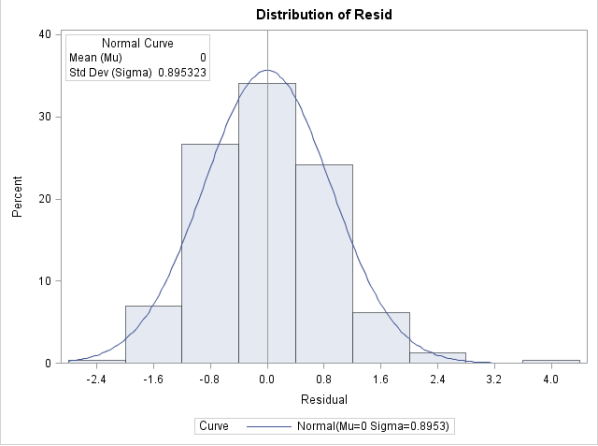



Delta lognormal CPUE index for Scalloped Hammerhead_GOM
Residuals positive CPUEs * Year
Residual
YEAR


Q-Q Plot for Resid
Normal Parameters
Mean (Mu) 0
Std Dev (Sigma) 0.895323
Residual
Normal Quantiles
Normal Line
Mu=0, Sigma=0.8953


Distribution of lgcpue
Normal Curve
Mean (Mu) 4.751672
Std Dev (Sigma) 1.127351
Percent
lgcpue
Curve
Normal(Mu=4.7517 Sigma=1.1274)


Delta lognormal CPUE index for Scalloped Hammerhead_GOM
Chisq Residuals proportion positive
raschi
YEAR


Distribution of Resid
Normal Curve
Mean (Mu) 0
Std Dev (Sigma) 0.895323
Percent
Residual
Curve
Normal(Mu=0 Sigma=0.8953)

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