Standardized abundance indices for scalloped hammerhead shark from the Pelagic Longline Observer Program, 1992-2019

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Introduction

In 1992, the National Marine Fisheries Service (NMFS) initiated scientific sampling of the U.S. large pelagic fisheries longline fleet, as mandated by the U.S. Swordfish Fisheries Management Plan and subsequently the Atlantic Highly Migratory Species Fishery Management Plan (1998). Scientific observers were placed aboard vessels participating in the Atlantic pelagic longline fishery. Relative abundance indices from data collected by observers have been previously developed and used in a variety of assessments of pelagic species primarily under the auspices of the International Commission for the Conservation of Atlantic Tunas (ICCAT). Herein, we develop an abundance time series for scalloped shark based on these data.

Methods

Data

The pelagic longline fishing grounds for the US fleet extend from the Grand Banks in the North Atlantic to 5-10° south, off the South American coast, including the Caribbean and the Gulf of Mexico. Eleven geographical areas of longline fishing are defined for classification (Figure 1): the Caribbean (CAR, area 1), Gulf of Mexico (GOM, area 2), Florida East coast (FEC, area 3), South Atlantic Bight (SAB, area 4), Mid-Atlantic Bight (MAB, area 5), New England coastal (NEC, area 6), Northeast distant waters (NED, or Grand Banks, area 7), Sargasso (SAR, area 8), North Central Atlantic (NCA, area 9), Tuna North (TUN, area 10), and Tuna South (TUN, area 11).

Catch rate analysis

A data set was developed based on the observer programs as described in Beerkircher et al. (2002) and Cortes et al. (2007. Following recommendations of the stock identification workshop, indices were developed for scalloped hammerhead for all areas, Atlantic Ocean and Gulf of Mexico.

For the purposes of analysis, several categorical and continuous variables were considered based on Cortes et al. (2007):

Categorical

- "Year"
  1992-2019
- "Target"
  BET, DOL, MIX, SHX, SWO, TUN, YFT
- "Fishing Area"
  CAR, FEC, GOM, MAB, NCA, NEC, NED, SAB, SAR, TUN, TUS, UNK
- "Season"
  Winter = January-March
  Spring = April-June
  Summer = July-September
  Fall = October-December
- "Bait": primary bait used
  ARTIF HERRI MACKE OTHER SARDI SCAD SQUID
- "Hook type": the hook that was used by the majority of the set
  CIRCLE, J HOOK, UNKNOW

- "Were lightsticks used"
  Yes, no

<u>Continuous</u>

- Mean Depth=(bottom_depth_minimum+bottom_depth_maximum/2)
- Mean Hook Depth=(mean_hook=(hook_depth_minimum+hook_depth_maximum/2)

Following previous methods in multiple SEDARs and Cortes et al. (2007), 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:

$$CPUE=\log [(\text{sharks kept}+\text{sharks released})/(\text{number of hooks}/1{,}000)]$$

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 ($p\leq0.05$) 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

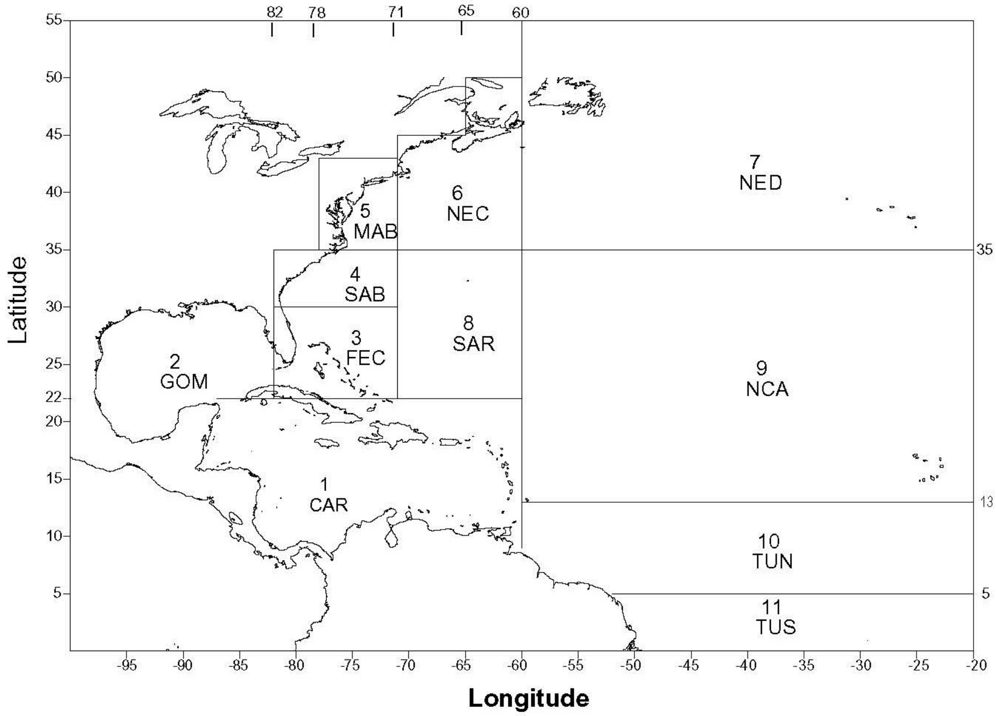


Figure 1. Map of the western North Atlantic Ocean. Areas are as follows: 1) Caribbean Sea (CAR), 2) Gulf of Mexico (GOM), 3) Florida East coast (FEC), 4) South Atlantic Bight (SAB), 5) Mid-Atlantic Bight (MAB), 6) New England coastal (NEC), 7) Northeast distant waters (NED or Grand Banks), 8) Sargasso Sea (SAR), 9) North Central Atlantic (NCA), 10) Tuna North (TUN), and 11) Tuna South (TUN).

All Areas

The proportion of positive sets (i.e. at least one shark was caught) was 4.5%. 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 scalloped hammerhead for all areas.

Proportion positive-Binomial error distribution					
FACTOR	**DEVIANCE/DF**	**%DIFF**	**DELTA%**	**CHISQUARE**	**PR>CHI**
NULL	0.3837				
YEAR	0.3769	1.772	1.772	118.43	<.0001
YEAR+					

MEAN_DEPTH	0.3107	19.025	17.253	1048.77	<.0001
FISHING_AREA	0.3559	7.245		Negative of Hessian not positive definite	
BAIT_1	0.3693	3.753		123.26	<.0001
TARGET	0.3694	3.727		120.36	<.0001
SEASON	0.3699	3.597		112.12	<.0001
MEAN_HOOK_DEPTH	0.3749	2.293		32.26	<.0001
HOOK_TYPE_1	0.3753	2.189		25.99	<.0001
WERE_LIGHT_SICKS_USED	0.3764	1.903		7.71	0.0055
SST	0.3767	1.824		3.88	0.0488
YEAR+MEAN_DEPTH+					
SEASON	0.301	21.553	2.528	154.87	<.0001
MEAN_HOOK_DEPTH	0.3095	19.338		18.95	<.0001
SST	0.31	19.208		11.6	0.0007
BAIT_1	0.3102	19.156		9.38	0.1531
HOOK_TYPE_1	0.3102	19.156		9.21	0.01
TARGET	0.3103	19.130		8.1	0.231
WERE_LIGHT_SICKS_USED	0.3106	19.051		2.72	0.0988
YEAR+MEAN_DEPTH+SEASON+					
SST	0.3005	21.684	0.130	7.64	0.0057
MEAN_HOOK_DEPTH	0.301	21.553		0.59	0.443
PROPORTION POSITIVE	**AIC**				
YEAR+MEAN_DEPTH+SEASON	108523.5				
YEAR*MEAN_DEPTH	108523.5				
YEAR*SEASON	108523.5				

Positive catches-Lognormal error distribution					
FACTOR	**DEVIANCE/DF**	**%DIFF**	**DELTA%**	**CHISQUARE**	**PR>CHI**
NULL	1.0464				
YEAR	1.0031	4.138	4.138	60.39	0.0002
YEAR+					
MEAN_DEPTH	0.9081	13.217	9.079	76.33	<.0001
TARGET	0.9527	8.955		46.33	<.0001
FISHING_AREA	0.9676	7.531		37.43	<.0001
SEASON	0.9812	6.231		20.26	0.0002
BAIT_1	0.9897	5.419		15.65	0.0079
SST	0.9932	5.084		7.06	0.0079
HOOK_TYPE_1	1.0023	4.214		2.66	0.264
MEAN_HOOK_DEPTH	1.0036	4.090		0.63	0.4266
WERE_LIGHT_SICKS_USED	1.0038	4.071		0.44	0.5072
YEAR+MEAN_DEPTH+					
FISHING_AREA	0.8686	16.992	3.775	43.31	<.0001
TARGET	0.8794	15.959		30.76	<.0001

SEASON	0.8873	15.205		20.82	0.0001
SST	0.9004	13.953		7.06	0.0079
BAIT_1	0.9047	13.542		8.03	0.1544
YEAR+MEAN_DEPTH+FISHING_AREA+					
TARGET	0.8387	19.849	2.857	33.11	<.0001
SEASON	0.8505	18.721		19.26	0.0002
SST	0.863	17.527		4.9	0.0269
YEAR+MEAN_DEPTH+FISH_AREA+TARGET+					
SEASON	0.824	21.254	1.405	16.65	0.0008
SST	0.834	20.298		3.66	0.0556
POSITIVE	**AIC**				
YEAR+MEAN_DEPTH+FISH_AREA+TARGET+SEASON	2470				
YEAR*MEAN_DEPTH	2462.2				
YEAR*FISH_AREA	2462.2				
YEAR*TARGET	2461.2				
YEAR*SEASON	2464.8				

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	StdErr	N	Standardized index	LCL	UCL	CV
1992	0.860	0.129	318	0.174	0.046	0.654	0.741
1993	0.350	0.035	817	0.062	0.022	0.178	0.565
1994	0.299	0.029	645	0.045	0.014	0.147	0.645
1995	0.224	0.024	696	0.039	0.012	0.123	0.629
1996	0.072	0.017	361	0.014	0.002	0.096	1.231
1997	0.225	0.051	458	0.070	0.019	0.257	0.729
1998	0.558	0.068	287	0.077	0.017	0.349	0.880
1999	0.091	0.019	430	0.018	0.003	0.104	1.066
2000	0.158	0.013	475	0.017	0.004	0.066	0.772
2001	0.261	0.042	403	0.052	0.013	0.213	0.807
2002	0.117	0.023	350	0.017	0.002	0.130	1.319
2003	0.151	0.030	558	0.038	0.010	0.154	0.785
2004	0.106	0.027	644	0.035	0.009	0.136	0.772
2005	0.174	0.026	552	0.040	0.012	0.130	0.642
2006	0.339	0.039	570	0.050	0.013	0.198	0.777
2007	0.168	0.029	949	0.049	0.016	0.146	0.591
2008	0.521	0.037	1213	0.073	0.029	0.188	0.497
2009	0.469	0.045	1384	0.101	0.043	0.238	0.449
2010	0.669	0.041	887	0.084	0.033	0.212	0.488
2011	0.624	0.026	888	0.054	0.022	0.135	0.481

2012	0.358	0.048	953	0.101	0.041	0.247	0.471
2013	0.292	0.021	1486	0.046	0.019	0.111	0.458
2014	0.125	0.021	1234	0.038	0.014	0.106	0.551
2015	0.162	0.020	1142	0.039	0.015	0.102	0.516
2016	0.310	0.022	1228	0.041	0.015	0.110	0.521
2017	0.896	0.038	901	0.073	0.027	0.196	0.523
2018	0.178	0.023	731	0.033	0.009	0.114	0.688
2019	0.075	0.014	506	0.015	0.003	0.074	0.918

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.

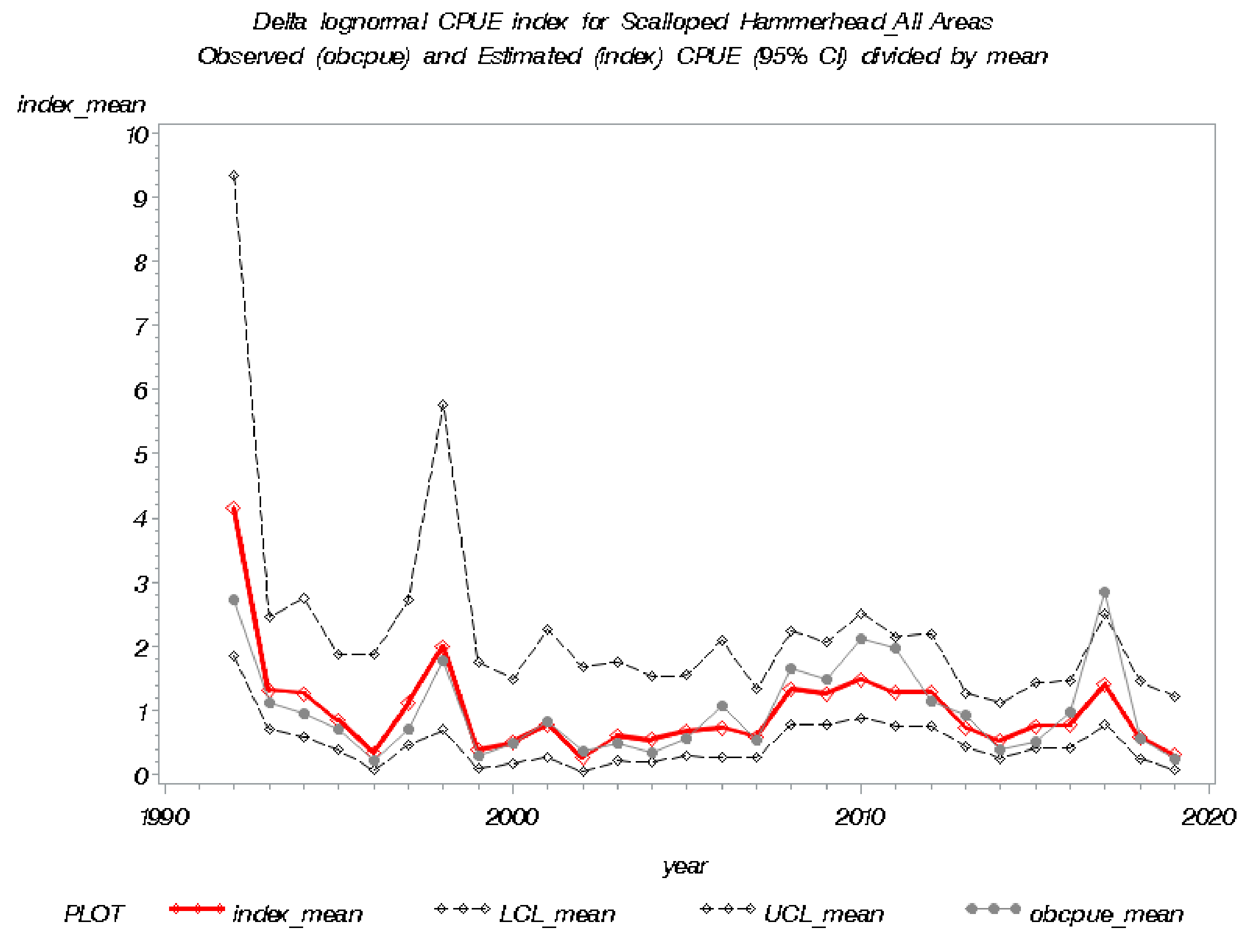
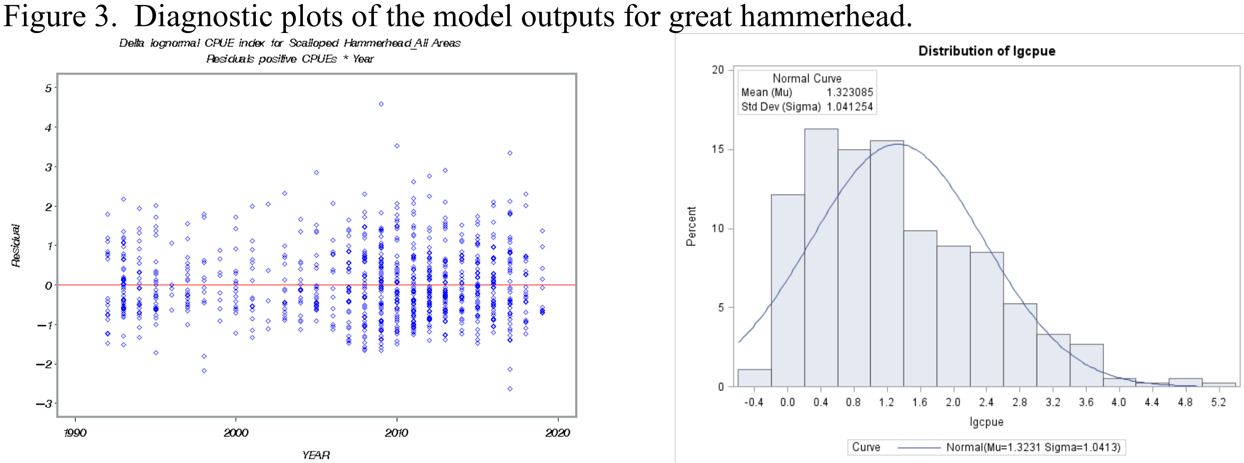
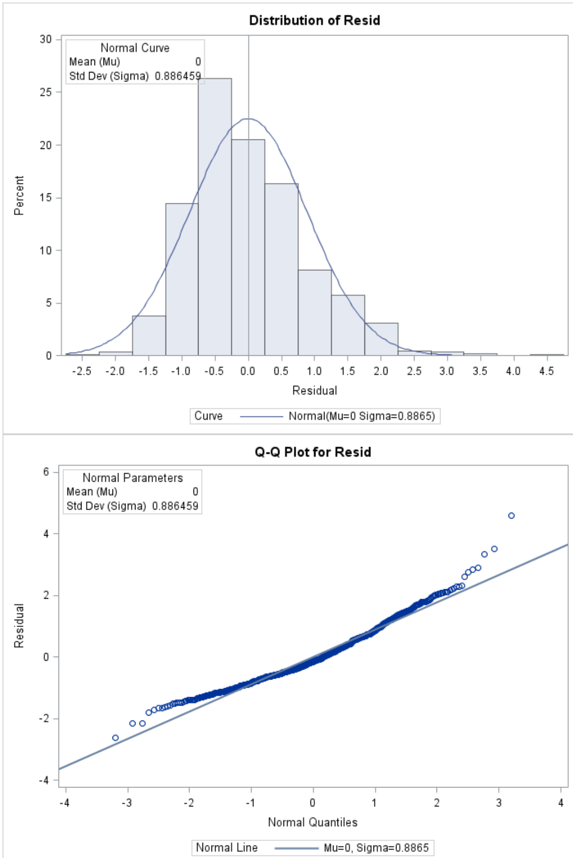
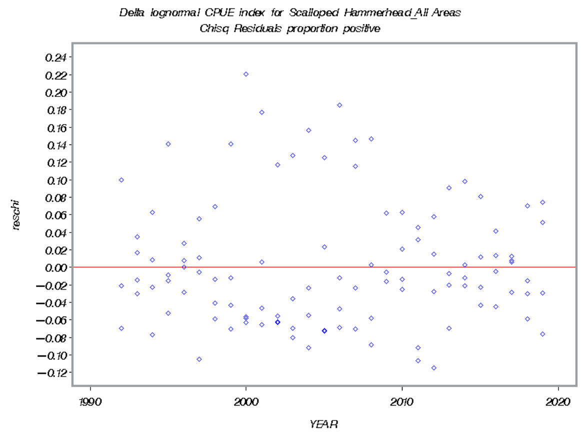


Figure 3. Diagnostic plots of the model outputs for great hammerhead.







Atlantic Ocean

The proportion of positive sets (i.e. at least one shark was caught) was 4.9%. 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 the Atlantic Ocean.

Proportion positive-Binomial error distribution					
FACTOR	**DEVIANCE/DF**	**%DIFF**	**DELTA%**	**CHISQUARE**	**PR>CHI**
NULL	0.5018				
YEAR	0.4937	1.614	1.614	69.11	<.0001
YEAR+					
TARGET	0.3944	21.403	19.789	38.99	<.0001
SST	0.3957	21.144		24.81	<.0001

WERE_LIGHT_SICKS_USED	0.3967	20.945		15.18	<.0001
MEAN_DEPTH	0.4307	14.169		431.77	<.0001
FISHING_AREA	0.4462	11.080		Negative of Hessian not positive definite	
SEASON	0.4837	3.607		70.25	<.0001
BAIT_1	0.4915	2.053		Negative of Hessian not positive definite	
HOOK_TYPE_1	0.4924	1.873		10.17	0.0062
MEAN_HOOK_DEPTH	0.4929	1.774		5.71	0.0168
YEAR+TARGET+					
MEAN_DEPTH	0.3497	30.311	8.908	410.71	<.0001
SEASON	0.3875	22.778		63.75	<.0001
SST	0.3911	22.061		29.83	<.0001
HOOK_TYPE_1	0.3932	21.642		11.59	0.003
WERE_LIGHT_SICKS_USED	0.3939	21.503		4.57	0.0325
MEAN_HOOK_DEPTH	0.3944	21.403		0.25	0.6162
YEAR+TARGET+MEAN_DEPTH+					
SEASON	0.3415	31.945	**1.634**	76.26	<.0001
SST	0.347	30.849		24.42	<.0001
HOOK_TYPE_1	0.3485	30.550		10.91	0.0043
WERE_LIGHT_SICKS_USED	0.349	30.450		6.37	0.0116
YEAR+TARGET+MEAN_DEPTH+SEASON+					
SST	0.3393	32.383	0.438	19.8	<.0001
HOOK_TYPE_1	0.3408	32.084		7.06	0.0293
WERE_LIGHT_SICKS_USED	0.3407	32.104		7.57	0.006
PROPORTION POSITIVE	**AIC**				
YEAR*TARGET	54108.8				
YEAR*MEAN_DEPTH	54344.7				
YEAR*SEASON	55433.1				
YEAR+TARGET+MEAN_DEPTH+SEASON	55504.3				

Positive catches-Lognormal error distribution					
FACTOR	**DEVIANCE/DF**	**%DIFF**	**DELTA%**	**CHISQUARE**	**PR>CHI**
NULL	1.0158				
YEAR	0.9565	5.838	5.838	56.4	0.0008
YEAR+					
TARGET	0.9147	9.953	4.115	27.66	0.0001
FISHING_AREA	0.927	8.742		23.5	0.0028
MEAN_DEPTH	0.9273	8.712		16.74	<.0001
SEASON	0.9333	8.122		14.85	0.0019
WERE_LIGHT_SICKS_USED	0.954	6.084		2.31	0.1282
BAIT_1	0.958	5.690		2.47	0.4813
MEAN_HOOK_DEPTH	0.9583	5.661		0.16	0.6863
SST	0.9589	5.601		0.49	0.4834

HOOK_TYPE_1	0.9604	5.454		0.22	0.8959
YEAR+TARGET+					
FISHING_AREA	0.8851	12.867	2.914	24.34	0.002
MEAN_DEPTH	0.8874	12.640		16.37	<.0001
SEASON	0.8942	11.971		13.99	0.0029
YEAR+TARGET+FISHING_AREA+					
SEASON	0.8682	14.530	1.664	12.47	0.0059
MEAN_DEPTH	0.8687	14.481		10.86	0.001
YEAR+TARGET+FISHING_AREA+SEASON					
MEAN_DEPTH	0.8489	16.430	1.900	12.84	0.0003
POSITIVE	**AIC**				
YEAR*SEASON	1664.2				
YEAR*TARGET	1665.1				
YEAR*FISHING_AREA	1669.2				
YEAR+TARGET+FISHING_AREA+SEASON	1669.7				

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
1992	0.651	0.132	257	0.232	0.080	0.670	0.571
1993	0.410	0.046	586	0.100	0.042	0.239	0.459
1994	0.354	0.045	491	0.087	0.033	0.229	0.517
1995	0.301	0.041	489	0.085	0.034	0.213	0.486
1996	0.062	0.019	233	0.022	0.005	0.096	0.842
1997	0.342	0.078	291	0.145	0.053	0.398	0.538
1998	0.732	0.079	219	0.130	0.042	0.398	0.608
1999	0.154	0.029	247	0.038	0.010	0.148	0.761
2000	0.253	0.032	296	0.059	0.021	0.165	0.553
2001	0.469	0.073	200	0.122	0.040	0.367	0.596
2002	0.213	0.037	192	0.041	0.009	0.189	0.884
2003	0.120	0.044	290	0.069	0.022	0.221	0.632
2004	0.163	0.042	376	0.068	0.022	0.210	0.617
2005	0.348	0.062	256	0.116	0.043	0.315	0.530
2006	0.576	0.073	300	0.122	0.041	0.368	0.594

2007	0.371	0.093	330	0.189	0.075	0.480	0.492
2008	0.523	0.052	380	0.095	0.034	0.263	0.543
2009	0.740	0.079	519	0.174	0.073	0.414	0.456
2010	0.647	0.058	509	0.144	0.066	0.314	0.406
2011	0.506	0.045	552	0.097	0.040	0.234	0.462
2012	0.415	0.088	506	0.201	0.087	0.463	0.437
2013	0.042	0.015	648	0.025	0.009	0.074	0.578
2014	0.084	0.024	674	0.047	0.018	0.123	0.513
2015	0.228	0.042	721	0.097	0.042	0.221	0.432
2016	0.468	0.040	697	0.092	0.040	0.211	0.432
2017	1.302	0.061	608	0.152	0.070	0.330	0.402
2018	0.289	0.038	421	0.070	0.026	0.192	0.536
2019	0.093	0.023	381	0.035	0.010	0.115	0.658

Figure 4. 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.

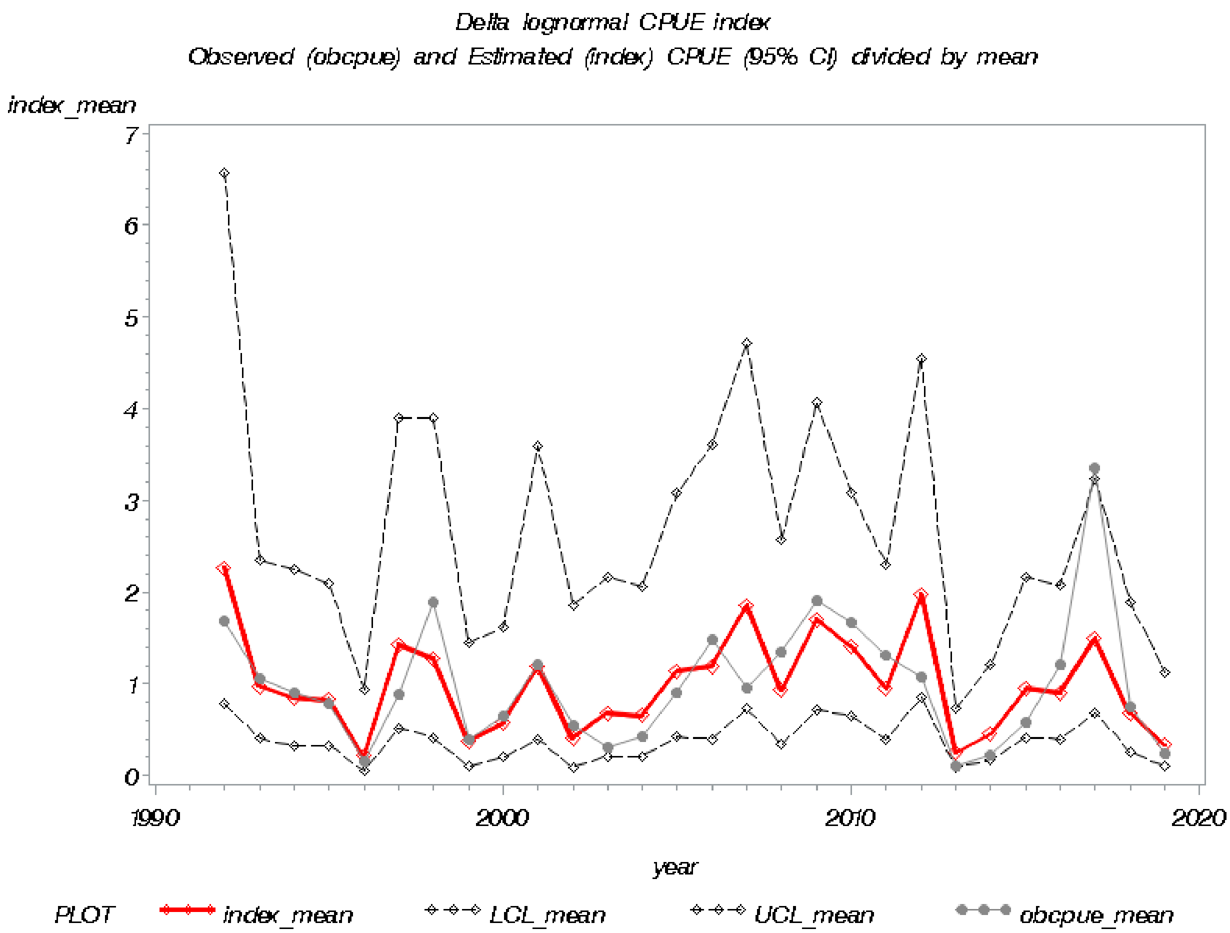
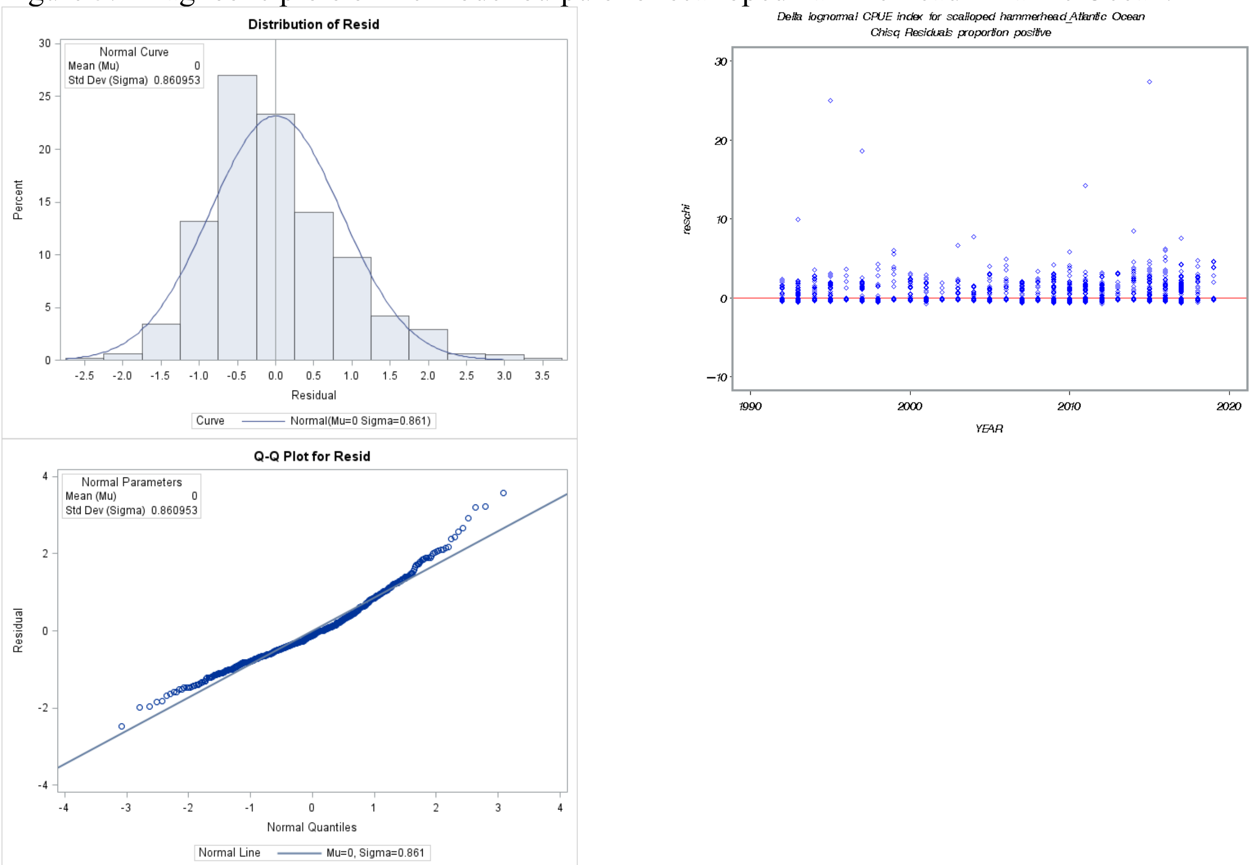


Figure 5. Diagnostic plots of the model outputs for scalloped hammerhead-Atlantic Ocean.



Gulf of Mexico

A relative abundance index could not be constructed for the Gulf of Mexico. In the initial identification of covariates any model that used the covariate “year” resulted in the negative of Hessian not positive definite.

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