STANDARDIZED CATCH RATES OF BLUE SHARKS IN THE WESTERN NORTH ATLANTIC OCEAN FROM THE U.S. PELAGIC LONGLINE OBSERVER PROGRAM 1992-2014 AND 2015-2021

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SUMMARY

*An updated index of abundance was developed for blue shark (*Prionace glauca*) from data collected by the U.S. pelagic longline fishery observer program (1992-2021). The U.S. pelagic longline CPUE was estimated for two separate periods (1992-2014 and 2015-2021) to account for changes in U.S. management regulations that could not be included in the standardization process. The indices were calculated using a two-step delta-lognormal approach that treats the proportion of positive sets and the CPUE of positive catches separately. Observations affected by fishing regulations such as time-area closures or bait restrictions were excluded in this analysis. The standardized indices with 95% confidence intervals are reported. The standardized index 1992-2014 showed an initial increasing trend from 1992 to 1998, followed by a decrease to 2003, an increase to 2011, and a subsequent decrease to 2014. The standardized index 2015-2021 showed an overall decreasing trend.*

RÉSUMÉ

*Un indice d'abondance actualisé a été développé pour le requin peau bleue (*Prionace glauca*) à partir des données collectées par le programme d'observateurs de la pêche pélagique palangrière des États-Unis (1992-2021). La CPUE des palangriers pélagiques américains a été estimée pour deux périodes distinctes (1992-2014 et 2015-2021) afin de tenir compte des changements dans les réglementations de gestion américaines qui n'ont pas pu être inclus dans le processus de standardisation. Les indices ont été calculés au moyen d'une approche delta-lognormale en deux étapes qui traite séparément la proportion d'opérations positives et la CPUE des captures positives. Les observations affectées par des réglementations de pêche telles que les fermetures spatio-temporelles ou les restrictions sur les appâts ont été exclues de cette analyse. Les indices standardisés avec des intervalles de confiance à 95% sont déclarés. L'indice standardisé de 1992-2014 présentait une tendance initiale à la hausse de 1992 à 1998, suivie d'une baisse jusqu'en 2003, d'une hausse jusqu'en 2011 et d'une baisse ultérieure jusqu'en 2014. L'indice standardisé 2015-2021 affichait une tendance globale à la baisse.*

RESUMEN

*Se desarrolló un índice actualizado de abundancia para el tiburón azul (*Prionace glauca*) a partir de los datos recogidos por el programa de observadores de la pesquería de palangre pelágico de Estados Unidos (1992-2021). La CPUE de palangre pelágico de Estados Unidos se estimó para dos periodos diferentes (1992-2014 y 2015-2021) para tener en cuenta los cambios en los reglamentos de ordenación estadounidenses que no pudieron incluirse en el proceso de estandarización. Los índices se calcularon utilizando un enfoque delta-lognormal de dos etapas que trata la proporción de lances positivos y la CPUE de las capturas positivas por separado. En este análisis se excluyeron las observaciones afectadas por reglamentaciones pesqueras como las vedas espaciotemporales o las restricciones de cebo. Se comunican los índices estandarizados con intervalos de confianza del 95 %. El índice estandarizado 1992-2014 mostraba una tendencia inicial creciente de 1992 a 1998, seguida de un descenso hasta 2003,*

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un aumento hasta 2011 y un posterior descenso hasta 2014. El índice estandarizado 2015-2021 mostró una tendencia global decreciente.

KEYWORDS

Catch/effort, Commercial fishing, Longlining, Pelagic fisheries, Shark fisheries, Observer programs, Blue shark

1. Introduction

A relative abundance index from the U.S. commercial pelagic longline fishery observer program was generated and used in the 2004, 2008, and 2015 ICCAT assessments of blue sharks (ICCAT 2005, 2009, 2016). In this document, the commercial series is updated to examine recent trends in abundance of blue sharks for use in the 2023 stock assessment of the North Atlantic stock. Indices of abundance for blue sharks from the U.S. commercial pelagic longline fishery observer program were previously developed by Brooks et al. (2005), Cortés (2007; 2009, 2016), and Cortés *et al.*, (2007). The U.S. pelagic longline observer program managed by the U.S. NOAA/NMFS/Southeast Fisheries Science Center, currently has a target coverage of 8-percent of the longline sets deployed by the fleet. The U.S. pelagic longline observer program data were broken into two periods: 1992-2014 and 2015-2021 to account for changes in U.S. management regulations affecting its pelagic longline fleet. The two indices were calculated using a two-step delta-lognormal approach that treats the proportion of positive sets and the CPUE of positive catches separately.

2. Materials and Methods

2.1 Data

The pelagic longline fishing grounds for the U.S. fleet traditionally extended 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. However, reductions in the number of vessels actively participating in the longline fishery has reduced the area of operation of the fleet during the past few years. Eleven U.S. domestic geographical areas of longline fishing have traditionally been used to analyze fisheries data (**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).

Data from the U.S. pelagic longline observer program were available for 1992-2021. The observer dataset was restricted to areas 5, 6, and 7 (north of 35º North latitude) owing to insufficient and unbalanced blue shark catch observations by year in the remaining areas. Areas 5, 6, and 7 accounted for 90 and 89% of all observations in the observer dataset for period 1992-2014 and period 2015-2021, respectively (**Figure 2**).

Several data restrictions were implemented in the present analysis to account for time-area closures or bait restrictions following Walter and Lauretta (2015) and Cortés (2017). Due to the different effects of spatio-temporal closures in different areas, a single "closure" effect could not be considered because it would likely differ among areas and thus the most parsimonious approach was to exclude data from the entire time series before and after the closure for each area. More specifically, the following data restrictions were applied: (1) the DeSoto Canyon Closed Area in the Gulf of Mexico, closed year-round; (2) the East Florida Coast Closed Area, closed year-round; (3) the Charleston Bump Closed Area, closed February-April; (4) the Northeastern United States Closed Area, closed in June; (5) the Northeast Distant Gear Restricted Area, closed year-round except for specific bait-gear configurations; and (6) the Spring Gulf of Mexico Gear Restricted Areas, closed April-May (**Figure 1**).

Based on the methodology used by Brooks et al. (2005), Cortés (2007, 2009, 2016), and Cortés et al. (2007), the following factors were considered in the analysis: year, area, quarter (January-March, April-June, July-September, October-December), presence or absence of light sticks, and whether or not the data were part of experimental fishing (conducted in years 2000-2003 in the Northeast Distant area only). Additionally, nominal catch rates (catch per thousand hooks) of swordfish, *Xiphias gladius*, and tuna (the sum of albacore, *Thunnus alalunga*, skipjack, *Euthynnus pelamis*, bigeye, *Thunnus obesus*, and yellowfin tuna, *Thunnus albacares*) were calculated for each set, and a categorical factor based on the quartile of those catch rates was assigned to each set (the factors are denoted as Sqr and Tqr, respectively). The reason for creating these factors, which correspond to the <25%, 25-49%, 50-75%, and >75% of the proportion, was to attempt to control for effects of blue shark catch rates associated with changes of fishing operations when the fleets target species changed. We also considered the following interactions: year*area, year*quarter, as well as the interactions between area and the nominal catch rate quartiles for tuna and swordfish (area*Sqr and area*Tqr). Blue shark nominal and standardized CPUEs were defined/estimated as total catch per 1000 hooks where total catch included all retained, dead discarded, and live released blue sharks.

2.2 Analysis

Relative abundance indices were estimated using a Generalized Linear Modeling (GLM) approach assuming a delta lognormal model distribution. A binomial error distribution is used for modeling the proportion of positive sets with a logit function as link between the linear factor component and the binomial error. A lognormal error distribution is used for modeling the catch rates of successful sets, wherein estimated CPUE rates assume a lognormal distribution (lnCPUE) of a linear function of fixed factors. The models were fitted with the SAS GENMOD procedure using a forward stepwise approach in which each potential factor was tested one at a time. Initially, a null model was run with no explanatory variables (factors). Factors were then entered one at a time and the results ranked from smallest to greatest reduction in deviance per degree of freedom when compared to the null model. The factor which resulted in the greatest reduction in deviance per degree of freedom was then incorporated into the model if two conditions were met: 1) the effect of the factor was significant at least at the 5% level based on the results of a Chi-Square statistic of a Type III likelihood ratio test, and 2) the deviance per degree of freedom was reduced by at least 1% with respect to the less complex model. Single factors were incorporated first, followed by fixed first-level interactions. The year factor was always included because it is required for developing a time series. Results were summarized in the form of deviance analysis tables including the deviance for proportion of positive observations and the deviance for the positive catch rates.

Once the final model was selected, it was run using the SAS GLIMMIX macro (which itself uses iteratively reweighted likelihoods to fit generalized linear mixed models with the SAS MIXED procedure; Wolfinger and O'Connell 1993, Littell et al. 1996). In this model, any interactions that included the *year* factor were treated as a random effect. Goodness-of-fit criteria for the final model included Akaike's Information Criterion (AIC), Schwarz's Bayesian Criterion, and –2* the residual log likelihood (-2Res L). The significance of each individual factor was tested with a Type III test of fixed effects, which examines the significance of an effect with all the other effects in the model (SAS Institute Inc. 1999). The final mixed model calculated relative indices as the product of the year effect least squares means (LSMeans) from the binomial and lognormal components. LSMeans estimates were weighted proportionally to observed margins in the input data, and for the lognormal estimates, a back-transformed log bias correction was applied (Lo *et al.* 1992).

3. Results

3.1 Period 1 (1992-2014)

Factors retained for the blue shark proportion of positive sets were Sqr, year, Tqr, area, and quarter; and for the positive catches, the factors area, quarter, year, Sqr, Tqr, year*quarter, year*area, and Sqr*area were retained (**Table 1a**). The factor Sqr and the factor area explained 54.33% and 48.12% of the deviance for the proportion positive and positive catches, respectively (**Table 2a**). The estimated standardized CPUE and CV values are given in **Table 3a**. The nominal index showed an overall decreasing trend: specifically, a decreasing trend from 1992 to 2003, followed by an increase from 2003 to 2011, then followed by a decreasing tendency thereafter (**Figure 3a**). In contrast, the standardized index showed an initial increasing trend from 1992 to 1998, followed by a decrease to 2003, an increase to 2011, and a subsequent decrease to 2014. The sometimes large interannual fluctuations in the observer index may be due to small sample size (15 -274 positive sets per year; **Figure 3a**). Diagnostic plots showed some patterns in the residuals of the proportion positive sets (**Figure 4a**).

3.2 Period 2 (2015-2021)

Factors retained for the blue shark proportion of positive sets were quarter, area, Tqr, and year; and for the positive catches, the factors year, quarter, area, year*quarter, Tqr*area, and Sqr*area were retained (**Table 1b**). The factor quarter and the factor year*quarter explained 44.59% and 25.41% of the deviance for the proportion positive and positive catches, respectively (**Table 2b**). The estimated standardized CPUE and CV values are given in **Table 3b**. The nominal index showed an overall decreasing trend: specifically, a decreasing trend from 2015 to 2019, followed by an increase from 2019 to 2021 (**Figure 3b**). In contrast, the standardized index showed an initial increasing trend from 2015 to 2016, followed by a decrease to 2020, an increase to 2021. The sometimes large interannual fluctuations in the observer index may be due to small sample size (62 -210 positive sets per year; **Figure 3b**). Diagnostic plots showed some patterns in the residuals of the proportion positive sets (**Figure 4b**).

4. Discussion

Trends in relative abundance predicted from this analysis and a previous analysis (Cortés 2016) were similar during the overlapping years (1992-2013), with both series showing a concave shape, consisting of an initial decline to about the mid-2000s, followed by an increasing trend thereafter **(Figure 3a)**. However, the proportion of positive sets in 2001, 2002 and 2003 was much higher in the current analysis. This discrepancy may due to recent changes in the observer database, but it did not affect the predicted trends in relative abundance (**Figure 3a**). The observer dataset has small sample sizes leading to large interannual variation. Despite the fact that blue sharks are likely the most productive pelagic shark species (Cortés and Brooks 2018), sharp interannual changes in abundance, such as those sometimes displayed by the observer series are inconsistent with the biology of most sharks, whose stock abundance is expected to fluctuate relatively little from year to year. Similar to the finding of mako sharks based on the same U.S. longline observer program (Cortés 2017), considering the time-area closures did not appear to overly influence the predicted catch rates. It is also unlikely that other management actions, such as quota reductions, may have had any effect on the catch rates of blue sharks because the pelagic longline fishery in the USA has not traditionally targeted them, and catch rates used here are based on total catch (the sum of blue sharks kept, discarded dead and released alive). Other factors, such as hook size and type, were not included in the analysis, but may have affected catch rates of blue sharks. Fishing depth was indirectly taken into account in our analysis by using proxies for fishers targeting swordfish or tunas, but we did not differentiate between different species of tunas being targeted. The U.S. pelagic longline observer program data were broken into two periods: 1992-2014 and 2015-2021 to account for changes in U.S. management regulations. Up to 2014, U.S. pelagic longline vessels used to land blue sharks which allowed them to land a limited number of bluefin tuna. However, the adoption of a bluefin tuna IBQ (individual bycatch quota) for each individual vessel in the U.S. longline fleet allowed them to land bluefin tuna without the requirement of landing a certain required amount of other target species. Since there is absolutely no commercial value in catching blue sharks for the U.S. pelagic longline fleet, the fleet gradually changed their fishing behavior to avoid areas with large blue shark catches. Therefore, changes in the proportion of positives due to the changes in U.S. management regulations warranted the estimation of 2 separate CPUE series. However, this splitting does not seem to have affected the overall trend of this relative abundance index (**Table 4** and **Figure 5**).

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Table 1a. Factors retained in the model of proportion of positive sets and positive catch of blue sharks for the U.S. pelagic longline observer program data (1992-2014). The U.S. pelagic longline observer program data were broken into two periods: 1992-2014 and 2015-2021 to account for changes in U.S. management regulations.

Model factors proportion positives	DF	Deviance	Deviance/DF	%reduction	Log-likehood
Null	4031	4398	1.091		-2199
Sqr	4028	3871	0.961	11.92%	-1935
Sqr Year	4006	3712	0.927	3.59%	-1856
Sqr Year Tqr	4003	3562	0.890	3.95%	-1781
Sqr Year Tqr Area	4001	3490	0.872	1.99%	-1745
Final model: Sqr Year Tqr Area Quarter	3998	3428	0.857	1.70%	-1714

Model factors positive catch rates	DF	Deviance	Deviance/DF	%reduction	Log-likehood
Null	3083	4558	1.479		-4979
Area	3081	3576	1.161	21.50%	-4604
Area Quarter	3078	3184	1.034	10.87%	-4425
Area Quarter Year	3056	2998	0.981	5.15%	-4333
Area Quarter Year Sqr	3053	2942	0.964	1.79%	-4303
Area Quarter Year Sqr Tqr	3050	2893	0.949	1.56%	-4277
Area Quarter Year Sqr Tqr Year*Quarter	2990	2688	0.899	5.23%	-4164
Area Quarter Year Sqr Tqr Year*Quarter Year*Area	2961	2563	0.866	3.71%	-4091
Final model: Area Quarter Year Sqr Tqr Year*Quarter Year*area Sqr*Area	2955	2517	0.852	1.61%	-4063

Final model factors proportion positives

LR Statistics For Type 3 Analysis

Source	*DF*	*Chi-Square*	*Pr > ChiSq*
Sqr	3	312.13	<.0001
YEAR	22	129.82	<.0001
Tqr	3	114.52	<.0001
area	2	79.6	<.0001
quarter	3	61.81	<.0001

Final model factors positive catch rates

LR Statistics For Type 3 Analysis

Source	*DF*	*Chi-Square*	*Pr > ChiSq*
area	2	129.29	<.0001
quarter	3	207.39	<.0001
YEAR	22	84.51	<.0001
Sqr	3	12.24	0.0066
Tqr	3	50.38	<.0001
*quarter*YEAR*	60	205.49	<.0001
*area*YEAR*	29	145.16	<.0001
*area*Sqr*	6	56.35	<.0001

GLM Mixed Model	Neg2LogLike	AIC	BIC
Proportion Positives			
Sqr Year Tqr Area Quarter	5269	5270	5276
Positive catch rates			
Area Quarter Year Sqr Tqr Year*Quarter Year*area Sqr*area	8107	8113	8120

Table 1b. Factors retained in the model of proportion of positive sets and positive catch of blue sharks for the U.S. pelagic longline observer program data (2015-2021). The U.S. pelagic longline observer program data were broken into two periods: 1992-2014 and 2015-2021 to account for changes in U.S. management regulations.

Model factors proportion positives	DF	Deviance	Deviance/DF	%reduction	Log-likehood
Null	1625	2201	1.355		-1101
Quarter	1622	2020	1.245	8.08%	-1010
Quarter Area	1621	1895	1.169	6.15%	-947
Quarter Area Tqr	1618	1840	1.138	2.67%	-920
Final model: Quarter Area Tqr Year	1612	1794	1.113	2.14%	-897

Model factors positive catch rates	DF	Deviance	Deviance/DF	%reduction	Log-likehood
Null	958	1116	1.165		-1433
Year	952	1060	1.114	4.37%	-1409
Year Quarter	949	1023	1.078	3.25%	-1392
Year Quarter Area	948	953	1.005	6.72%	-1358
Year Quarter Area Year*Quarter	934	883	0.945	6.00%	-1321
Year Quarter Area Year*Quarter Tqr*Area	928	852	0.918	2.82%	-1304
Final model: Year Quarter Area Year*Quarter Tqr*Area Sqr*Area	926	839	0.906	1.74%	-1297

Final model factors proportion positives

LR Statistics For Type 3 Analysis

Source	*DF*	*Chi-Square*	*Pr > ChiSq*
quarter	3	204.86	<.0001
area	1	116.41	<.0001
Tqr	3	59.46	<.0001
YEAR	6	46.05	<.0001

Final model factors positive catch rates

LR Statistics For Type 3 Analysis

Source	*DF*	*Chi-Square*	*Pr > ChiSq*
YEAR	6	15.68	0.0156
quarter	3	67.57	<.0001
area	1	21.99	<.0001
*YEAR*quarter*	14	91.22	<.0001
*Tqr*area*	2	27.26	<.0001
*Sqr*area*	2	7.85	0.0197

GLM Mixed Model	Neg2LogLike	AIC	BIC
Proportion Positives			
Quarter Area Tqr Year	433	435	438
Positive catch rates			
Year Quarter Area Year*Quarter Tqr*Area Sqr*Area	2549	2553	2555

Table 2a. Deviance analysis table of explanatory variables in the delta lognormal model for blue shark catch rates (number of sharks per 1000 hooks) from the U.S. pelagic longline fishery observer program (1992-2014). The U.S. pelagic longline observer program data were broken into two periods: 1992-2014 and 2015-2021 to account for changes in U.S. management regulations.

Model factors proportion positives	Deviance	Change in deviance	% of total deviance
Null	4398		
Sqr	3871	527	54.33%
Sqr Year	3712	159	16.41%
Sqr Year Tqr	3562	149	15.40%
Sqr Year Tqr Area	3490	73	7.49%
Sqr Year Tqr Area Quarter	3428	62	6.37%

Model factors positive catch rates	Deviance	Change in deviance	% of total deviance
Null	4558		
Area	3576	983	48.12%
Area Quarter	3184	392	19.19%
Area Quarter Year	2998	186	9.09%
Area Quarter Year Sqr	2942	57	2.77%
Area Quarter Year Sqr Tqr	2893	49	2.39%
Area Quarter Year Sqr Tqr Year*Quarter	2688	205	10.05%
Area Quarter Year Sqr Tqr Year*Quarter Year*Area	2563	125	6.11%
Area Quarter Year Sqr Tqr Year*Quarter Year*Area Sqr*Area	2517	46	2.27%

Table 2b. Deviance analysis table of explanatory variables in the delta lognormal model for blue shark catch rates (number of sharks per 1000 hooks) from the U.S. pelagic longline fishery observer program (2015-2021). The U.S. pelagic longline observer program data were broken into two periods: 1992-2014 and 2015-2021 to account for changes in U.S. management regulations.

Model factors proportion positives	Deviance	Change in deviance	% of total deviance
Null	2201		
Quarter	2020	182	44.59%
Quarter Area	1895	125	30.81%
Quarter Area Tqr	1840	54	13.29%
Quarter Area Tqr Year	1794	46	11.30%
Model factors positive catch rates	**Deviance**	**Change in deviance**	**% of total deviance**
Null	1116		
Year	1060	55	19.99%
Year Quarter	1023	38	13.61%
Year Quarter Area	953	70	25.15%
Year Quarter Area Year*Quarter	883	70	25.41%
Year Quarter Area Year*Quarter Tqr*Area	852	30	10.97%
Year Quarter Area Year*Quarter Tqr*Area Sqr*Area	839	14	4.87%

Table 3a. Estimates of standardized CPUE (numbers of sharks per 1000 hooks) and coefficients of variation (CV) for blue sharks from the U.S. pelagic longline observer program data (1992-2014). The U.S. pelagic longline observer program data were broken into two periods: 1992-2014 and 2015-2021 to account for changes in U.S. management regulations.

Year	Standardized CPUE	CV	Nominal CPUE
1992	6.509	0.275	2.174
1993	10.04	0.254	2.445
1994	8.375	0.254	2.222
1995	8.532	0.258	2.065
1996	6.528	0.444	1.375
1997	12.53	0.289	2.483
1998	14.826	0.300	2.276
1999	6.997	0.282	2.414
2000	9.037	0.273	2.464
2001	4.588	0.330	1.794
2002	5.172	0.327	1.973
2003	3.619	0.302	1.176
2004	9.079	0.292	1.728
2005	3.228	0.302	1.216
2006	3.651	0.300	1.472
2007	6.357	0.321	1.405
2008	6.252	0.302	1.602
2009	5.961	0.301	1.738
2010	7.565	0.294	1.671
2011	13.688	0.279	2.321
2012	7.229	0.287	1.645
2013	6.882	0.285	1.845
2014	6.939	0.283	1.739

Table 3b. Estimates of standardized CPUE (numbers of sharks per 1000 hooks) and coefficients of variation (CV) for blue sharks from the U.S. pelagic longline observer program data (2015-2021). The U.S. pelagic longline observer program data were broken into two periods: 1992-2014 and 2015-2021 to account for changes in U.S. management regulations.

Year	Standardized CPUE	CV	Nominal CPUE
2015	5.196	0.286	2.095
2016	7.748	0.254	2.043
2017	6.978	0.250	1.785
2018	4.581	0.299	1.653
2019	3.596	0.289	1.400
2020	3.308	0.292	1.612
2021	4.081	0.308	1.857

Table 4. Estimates of standardized CPUE (numbers of sharks per 1000 hooks) and coefficients of variation (CV) for blue sharks from the pre-split U.S. pelagic longline observer program data (1992-2021). The U.S. pelagic longline observer program data were broken into two periods: 1992-2014 and 2015-2021 to account for changes in U.S. management regulations.

Year	Standardized CPUE	CV	Nominal CPUE
1992	6.109	0.270	2.174
1993	9.362	0.248	2.445
1994	8.270	0.247	2.222
1995	8.215	0.252	2.065
1996	6.030	0.446	1.375
1997	12.443	0.284	2.483
1998	14.726	0.293	2.276
1999	6.711	0.278	2.414
2000	9.441	0.267	2.464
2001	4.877	0.324	1.794
2002	5.813	0.318	1.973
2003	3.897	0.293	1.176
2004	8.941	0.285	1.728
2005	3.584	0.293	1.216
2006	3.914	0.292	1.472
2007	6.665	0.312	1.405
2008	6.844	0.294	1.602
2009	6.383	0.294	1.738
2010	7.451	0.286	1.671
2011	13.683	0.271	2.321
2012	7.184	0.279	1.645
2013	6.864	0.278	1.845
2014	6.487	0.275	1.739
2015	6.467	0.298	2.095
2016	8.442	0.274	2.043
2017	6.909	0.276	1.785
2018	4.027	0.342	1.653
2019	3.664	0.306	1.400
2020	3.505	0.307	1.612
2021	3.616	0.317	1.857

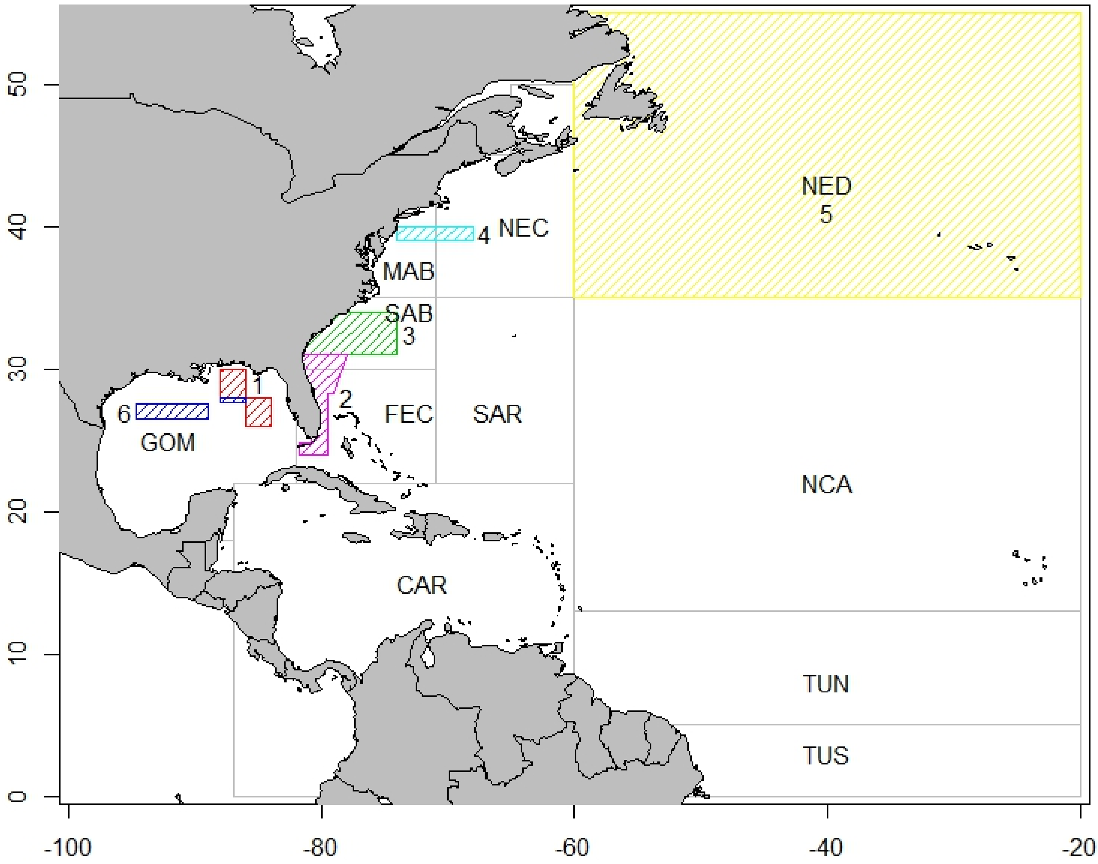
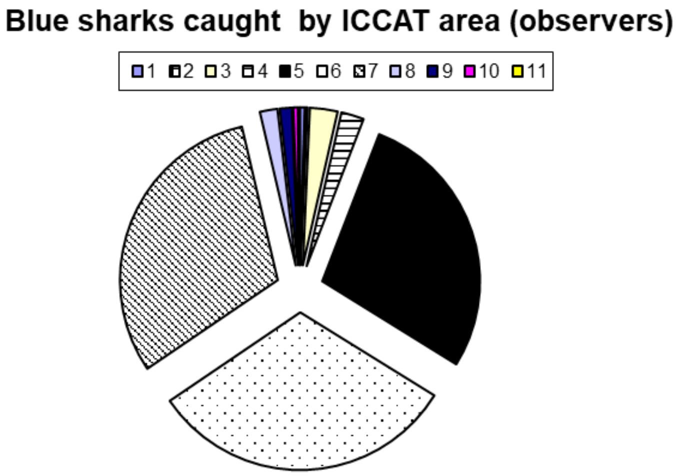


Figure 1. Map of the western North Atlantic Ocean. Areas are as follows: CAR=Caribbean (area 1); GOM=Gulf of Mexico (area 2); FEC=Florida East Coast (area 3); SAB=South Atlantic Bight (area 4); MAB=Mid-Atlantic Bight (area 5); NEC=Northeast Coastal (area 6); NED=Northeast Distant (area 7); SAR=Sargasso (area 8); NCA=North Central Atlantic (area 9); TUN=Tuna North (area 10); TUS=Tuna South (area 11). Time-area closures (designated by numbers in the map) are as follows: 1- DeSoto Canyon; 2- Florida East Coast; 3- Charleston Bump; 4- Bluefin tuna Northeast Atlantic; 5- Grand Banks; 6- Bluefin tuna spring Gulf of Mexico.



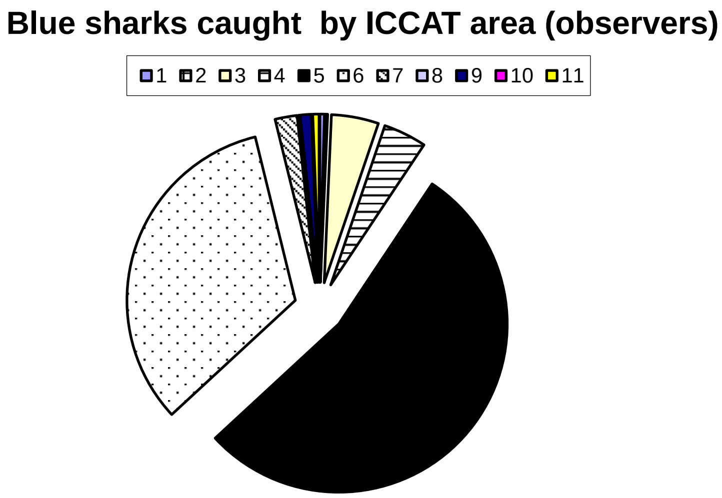


Figure 2. Blue sharks caught by ICCAT area as reported in the pelagic longline observer program for period 1992-2014 (top panel) and period 2015-2021 (bottom panel). Areas are as follows: CAR=Caribbean (area 1); GOM=Gulf of Mexico (area 2); FEC=Florida East Coast (area 3); SAB=South Atlantic Bight (area 4); MAB=Mid-Atlantic Bight (area 5); NEC=Northeast Coastal (area 6); NED=Northeast Distant (area 7); SAR=Sargasso (area 8); NCA=North Central Atlantic (area 9); TUN=Tuna North (area 10); TUS=Tuna South (area 11).

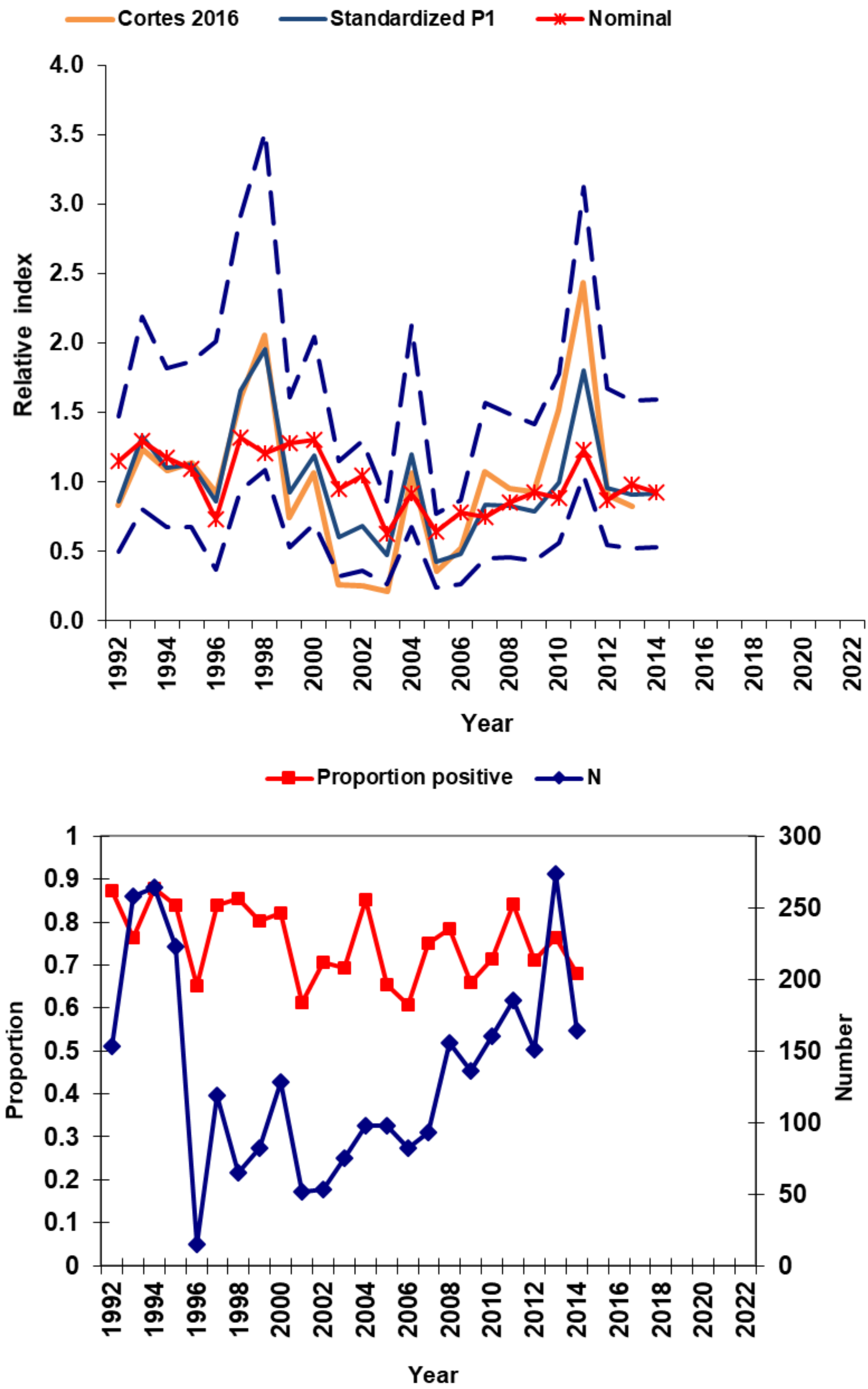


Figure 3a. Standardized CPUE (sharks/1000 hooks) and 95% confidence intervals for blue shark from the U.S. pelagic longline observer program (P1: 1992-2014) compared to a previous study. All indices are scaled to the mean of the overlapping years (1992-2013) for visualization purposes. The lower panel shows the proportion and number of positive sets by year. The U.S. pelagic longline observer program data were broken into two periods: 1992-2014 and 2015-2021 to account for changes in U.S. management regulations.

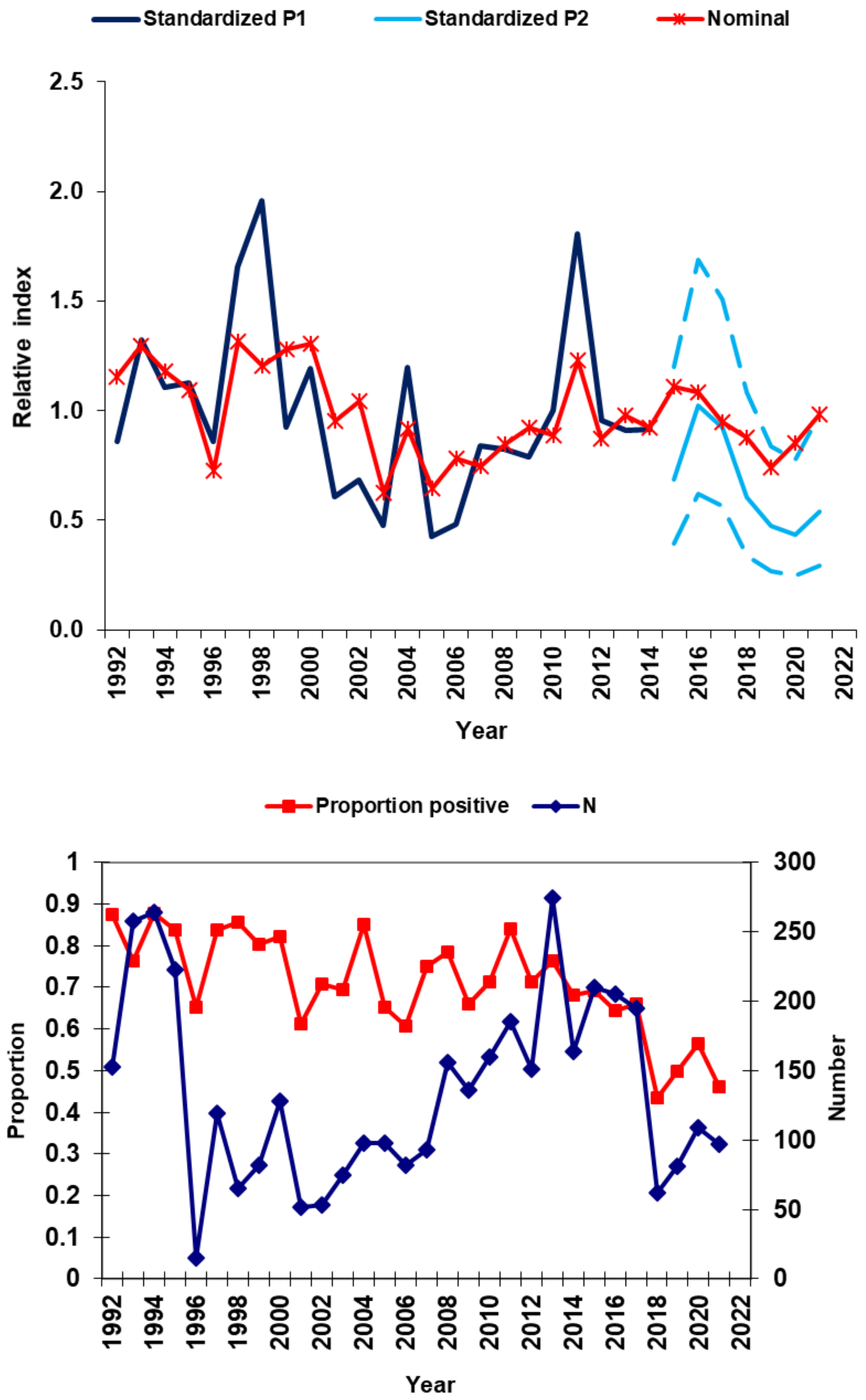


Figure 3b. Standardized CPUE (sharks/1000 hooks) and 95% confidence intervals for blue shark from the U.S. pelagic longline observer program (P2: 2015-2021) compared to standardized CPUE (sharks/1000 hooks) from the U.S. pelagic longline observer program (P1: 1992-2014). Even though there is no overlap between these two periods, both indices are scaled to the mean of the years (1992-2013) of index of period 1 for visualization purposes. The lower panel shows the proportion and number of positive sets by year. The U.S. pelagic longline observer program data were broken into two periods: 1992-2014 and 2015-2021 to account for changes in U.S. management regulations.

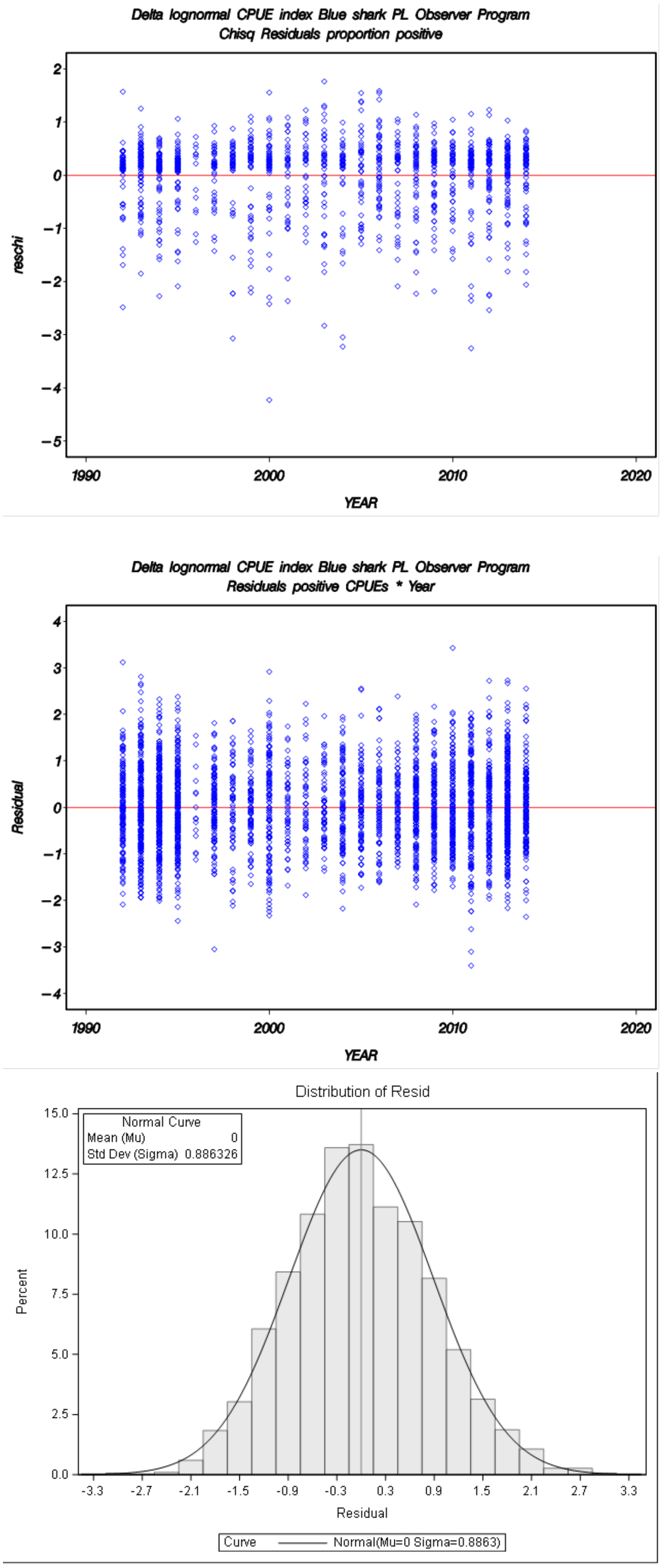


Figure 4a. Diagnostic plots of CPUE model from the U.S. pelagic longline observer data (1992-2014) for blue shark. Top: residuals of proportion positive sets; middle: residuals of positive catch; bottom: residual positive catch distribution. The U.S. pelagic longline observer program data were broken into two periods: 1992-2014 and 2015-2021 to account for changes in U.S. management regulations.

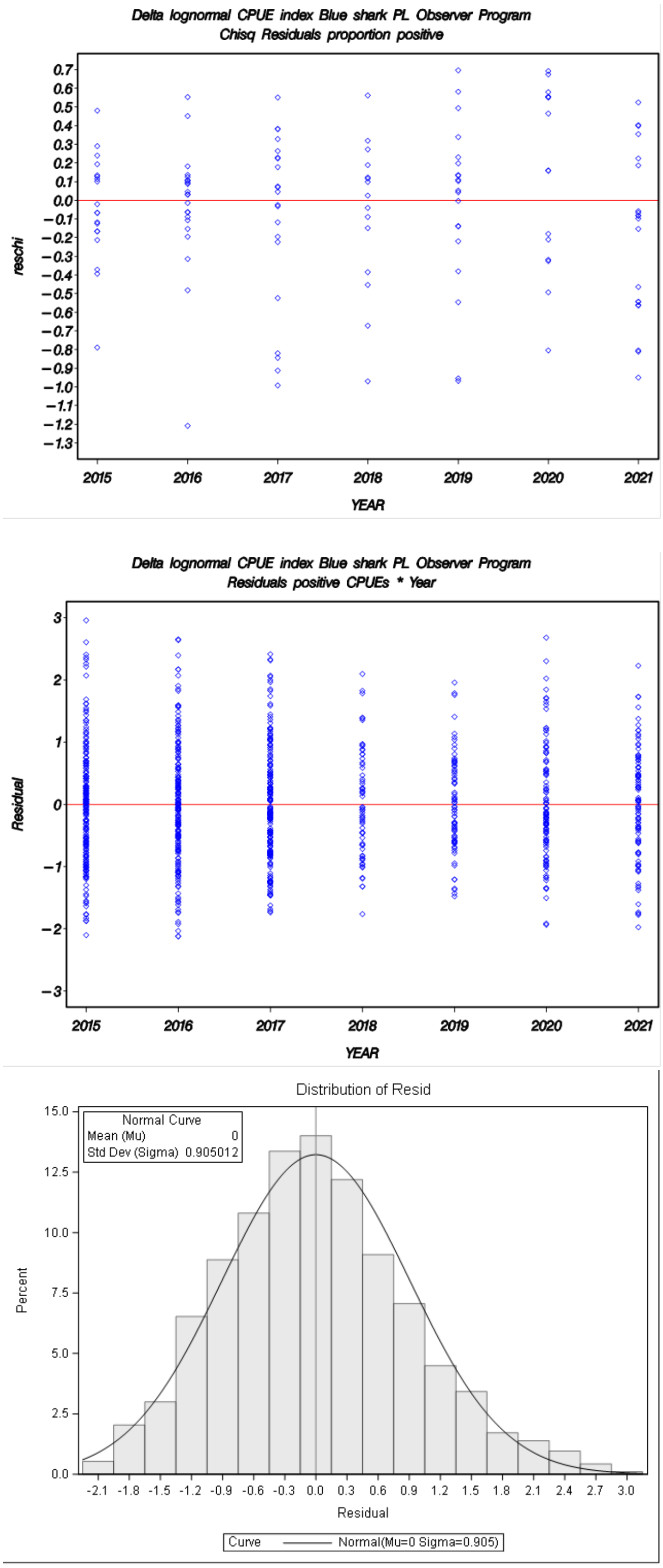


Figure 4b. Diagnostic plots of CPUE model from the U.S. pelagic longline observer data (2015-2021) for blue shark. Top: residuals of proportion positive sets; middle: residuals of positive catch; bottom: residual positive catch distribution. The U.S. pelagic longline observer program data were broken into two periods: 1992-2014 and 2015-2021 to account for changes in U.S. management regulations.

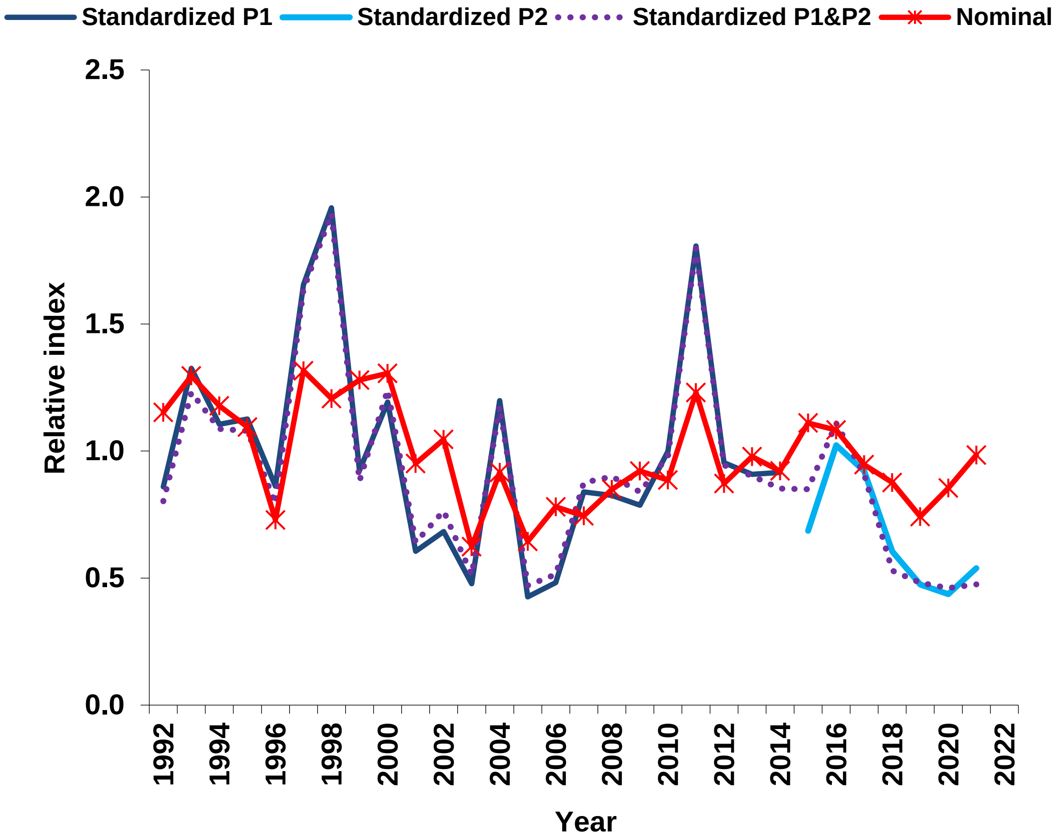


Figure 5. Standardized CPUE (sharks/1000 hooks) from the U.S. pelagic longline observer program for period 1992-2014 (P1) and period 2015-2021 (P2) compared to the pre-split time series (P1&P2: 1992-2021). Even though there is no overlap between these two periods, both indices are scaled to the mean of the years (1992-2013) of index of period 1 for visualization purposes. The U.S. pelagic longline observer program data were broken into two periods: 1992-2014 and 2015-2021 to account for changes in U.S. management regulations.