

STANDARDIZED CATCH RATES FOR YELLOWFIN TUNA (*THUNNUS ALBACARES*) FROM THE VENEZUELAN PELAGIC LONGLINE FISHERY IN THE CARIBBEAN SEA AND ADJACENT WATERS OF THE WESTERN CENTRAL ATLANTIC FOR THE PERIOD OF 1991-2018

M. Narváez¹, J. Alarcón¹, E. Evaristo², J.H. Marciano², X. Gutiérrez², F. Arocha^{1*}

SUMMARY

Standardized index of relative abundance for yellowfin tuna (*Thunnus albacares*) was estimated using Generalized Linear Models approach assuming a delta lognormal model distribution. For this, a combination of data sources (the Venezuelan Pelagic Longline Observer Program 1991-2011 and the National Observer Program 2012-2018) was used, considering as categorical variables year, season/quarter, condition and type of bait, vessel type, depth of fishing, and area. As indicators of overall model fitting, diagnostic plots were evaluated. The standardized yellowfin tuna catch rate index show relatively stable values through 2004 subsequently catch rates increased to a maximum in 2007. Thereafter, standardized catch rates showed a declining trend that appears to be stabilized during the last four years (2015-2018).

RÉSUMÉ

L'indice standardisé de l'abondance relative de l'albacore (*Thunnus albacares*) a été estimé en utilisant une approche de modèle linéaire généralisé (GLM) en postulant une distribution de modèle delta lognormal. A cet effet, on a eu recours à une combinaison de sources de données (le programme vénézuélien d'observateurs palangriers pélagiques 1991-2011 et le programme national d'observateurs 2012-2018), en considérant comme variables catégoriques : année, saison/trimestre, condition et type de l'appât, type de navire, profondeur de pêche et zone. Des diagrammes de diagnostic ont été évalués comme indicateurs de l'ajustement global du modèle. L'indice standardisé du taux de capture de l'albacore montre des valeurs relativement stables jusqu'en 2004 compris, puis les taux de capture ont augmenté pour atteindre un maximum en 2007. Par la suite, les taux de capture standardisés ont montré une tendance à la baisse qui semble s'être stabilisée au cours des quatre dernières années (2015-2018).

RESUMEN

El índice estandarizado de abundancia relativa de rabil (*Thunnus albacares*) se estimó utilizando un enfoque de modelos lineales generalizados (GLM) asumiendo una distribución de modelo delta lognormal. A este efecto, se utilizó una combinación de fuentes de datos (el programa de observadores de palangre pelágico de Venezuela 1991-2011 y el programa de observadores nacionales 2012-2018), considerando como variables categóricas año, temporada/trimestre, condición y tipo del cebo, tipo de buque, profundidad de pesca y área. Como indicadores del ajuste general del modelo, se evaluaron gráficos de diagnóstico. El índice de tasa de captura de rabil estandarizado muestra valores relativamente estables hasta 2004, posteriormente las tasas de captura aumentan hasta alcanzar un máximo en 2007. Posteriormente, las tasas de captura estandarizadas mostraban una tendencia decreciente que parece haberse estabilizado los últimos cuatro años (2015-2018).

KEY WORDS

Yellowfin tuna, Catch rates, Caribbean Sea, Venezuelan longline fishery

¹ Instituto Oceanográfico de Venezuela, Universidad de Oriente, Cumaná 6101 – Venezuela

² INSOPECA-Sucre, Cumaná 6101 - Venezuela

* Corresponding author: farocha@udo.edu.ve / farochap@gmail.com

Introduction

The nominal catch per effort (CPUE) has been used in many fisheries to assess the abundance fluctuations in several fish stocks worldwide. However, it requires standardization in order to consider the fluctuations owing to differences among geographical areas, changes in the fleet efficiency, and selectivity related issues. In this sense, yellowfin tuna (*Thunnus albacares*, YFT) is one of the species of great interest caught by the Venezuelan longline fleet operating in the Caribbean Sea and adjacent waters of the western central Atlantic, for which this type of estimation is of importance. The catch rate for *T. albacares* from Venezuelan longline fleet has shown signs of stability since 1991, with periods of higher catch rates in the 2000s (Marcano, 1999; Narváez *et al.*, 2017). The scientific observers from the ICCAT's Enhanced Billfish Research Program (EBRP) in Venezuela, who have been working on board of this fleet since 1991 (Arocha *et al.* 2013), have collected valuable data to develop standardized catch per unit of effort (CPUE) indices of abundance for the yellowfin tuna in earlier periods (Arocha *et al.*, 2001). Earlier estimations of this index for the yellowfin tuna caught by the Venezuelan longline fleet included mostly data from the EBRP; however, the most recent estimation (Narváez *et al.*, 2017) included additional data from the National Observer Program (2012-2014). In this document we present an updated standardized catch rate of yellowfin tuna using both sources of observer data from 1991 through 2018, using a Generalized Linear Model.

Materials and Methods

The main characteristics of the Venezuelan longline fleet is presented in Arocha & Marcano (2001) and a prior analysis to classify its vessels into three categories (Table 1) developed by Ortiz & Arocha (2004) was considered in the factors. The data collection used for modeling came from the ICCAT sponsored EPBR Venezuelan Pelagic Longline Observer Program (VPLOP) for the period (1991-2011) and from INSOPESCA's National Observer Program (Gassman *et al.*, 2014) for the period 2012-2018. A review of the available catch and effort data from Venezuelan pelagic longline fishery covered by the VPLOP showed that its observer coverage was on average 10.9% of the trips during 1991-2011 (Arocha *et al.* 2013), and under 5% from INSOPESCA's 2012-2018 observer program. Detailed information collected in the VPLOP, as well as fishing grounds for the Venezuelan fleet is the same as described in Ortiz & Arocha (2004). Factors included in the analysis were year, season (quarter of year), area of fishing, vessel category, bait condition (live or death), deep and type of bait. (**Table 1**). Fishing effort is reported in number of hooks per trip; catch rates were calculated as number of yellowfin tuna caught per 1000 hooks.

Generalized Linear Modelling approach was used to estimate the relative indices of abundance assuming delta lognormal model distribution (Arocha & Ortiz, 2010). This method involves the fitting of two models; modeling the records for which the catch is non-zero, and modeling the probability of non-zero catch (Lo *et al.*, 1992; Ortiz & Arocha, 2004). For the positive catch rates lognormal error distribution was assumed and binomial error distribution for the proportion of positive observations (positive sets/total sets). Interactions of year effect with other factors were modeled as random in the final model. Deviance analysis tables are presented for the two fitted models, from which selection of explanatory factors was made, considering the relative percent of deviance explained by adding the factor in the evaluation (factors that explained more than 5% were selected) and the Chi squared significance.

The final model selection was based in Akaike's Information Criterion (AIC), the Bayesian Information Criterion (BIC) and the likelihood ratio test (Faraway, 2006). Relative indices for the delta model formulation were calculated as the product of the year effect least square means (LSMeans) from the binomial and the lognormal model components. Quarter-year effect was not used for the LSMeans and final estimations owing to the lack of data for some quarters of the last years. Analyses were done using the statistical computer software R (R Core Team, 2018).

Results and discussion

Yellowfin tuna spatial distribution of nominal CPUE from the VPLOP and INSOPESCA's data sets is presented in **figure 1**. Important catch rates were obtained in the Caribbean Sea area (=area 1) towards the central Caribbean and east of the Orinoco Delta (Venezuela) and northeast of Surinam (=area 2). In most recent years (2016 onward), there has been a consistent increase in operations further eastward (50°- 45°W) in the Atlantic side, that the low observer coverage makes it difficult recognize.

Model diagnostics for the positive catch rates and for proportion of positive, include plots for a check of the link function, the variance function, the check for the error distribution of the model, and the qq-plot (normalized cumulative quartile plot) of the standardized deviance residuals (**Figures 2 and 3**). All diagnostic plots show no strong indication of departure from the expected or null pattern; results indicate no strong departures from the expected pattern (i.e., a constant range about the zero line). However, there are some departures from the expected null pattern in both model components that could not be explained. It is possible that it could be caused the uncommon operations of the fleet in response to economic factors affecting fleet operations, and/or the low observer coverage in recent years, but will require further analyses to confirm it.

As presented in **Table 2**, mayor factors that explained whether or not a set caught at least one fish were: *Year*, *Area*, *Vessel category (CatVess)*, *Bait condition (Bcond)*, *Year*Quart*, *Year*Area*, *Year*Btype*. On the other hand, for the proportion of positive/total sets; *Year*, *Area*, *Bait type (Btype)*, *Year*Quart*, *Year*Area*, *Year*CatVess*, were more significant.

Analyses of delta lognormal model formulations (**Table 3**), considering the values of AIC (Akaike's Information Criterion), BIC (Bayesian Information Criterion) and Log Likelihood as indicator of model fit, the selection of the final submodel for positive catch rates was: *Year*, *Area*, *Vessel*, *Bcond* as main fixed factor and the interactions, *Year*Season*, *Year*Area* and *Year*Btype*. Regarding to proportion of positive observations, the final submodel had as main factors: *Year*, *Area*, *Btype* and as interactions *Year*Quart*, *Year*Area*, *Year*CatVess* and *Year*Btype*.

These final submodels, explained 61.32% of the variability within the proportion of positive/total sets for the yellowfin tuna data, and 76.87% of the variability within the mean CPUE rates of positive catch sets.

Table 4 and **Figure 3** present normal and standardized CPUE. The standard deviation of the standardized CPUE, varied over the years. Nominal and standardized CPUEs show similar overall trends. Standardized YFT catch rates during the early period (1991-2004) was relatively stable with a few quarterly peaks, thereafter catch rates increased to a maximum in 2007. After 2007, standardized catch rates showed a declining trend that appears to be stabilized during the last four years (2015-2018). However, this trend is not clear due to the low observer coverage during this period, in which the fleet effort has remained somewhat stable and catches have increased notably in the last couple of years.

References

- Arocha, F., M. Ortiz, and L. Marciano. 2001. Standardized catch rates for yellowfin tuna (*Thunnus albacares*) from the Venezuelan pelagic longline fishery off the Caribbean Sea and the Western Central Atlantic. ICCAT, Col. Vol. Sci. Pap., 52:177-189.
- Arocha, F and M. Ortiz. 2010. Standardized catch rates for sailfish (*Istiophorus albicans*) from the Venezuelan pelagic longline fishery off the Caribbean Sea and adjacent areas: An update for 1991-2007. ICCAT, Col. Vol. Sci. Pap., 65: 1647- 1660.
- Arocha, F., L.A. Marciano, and J. Silva. 2013. Description of the Venezuelan pelagic longline observer program (VPLOP) sponsored by the ICCAT Enhanced Research Program for Billfish. ICCAT, Col. Vol. Sci. Pap., 69: 1333- 1342.
- Faraway, J. J. 2006. *Extending the linear model with R: Generalized Linear, Mixed Effects and Nonparametric Regression Models*. Chapman & Hall/CRC, Taylor & Francis Group. 301 pp.
- Gassman, J., C. Laurent, and J.H. Marciano. 2014. Ejecución del programa nacional de observadores a bordo de la flota industrial atunera venezolana del mar Caribe y océano Atlántico año 2012. ICCAT-Col. Vol. Sci. Pap., 70:2207-2216.
- Lo, N.C., L.D. Jacobson and J.L. Squire. 1992. Indices of relative abundance from fish spotter data based on delta-lognormal models. Can. J. Fish. Aquat. Sci. 49: 2515–2526.
- Narvaéz, M., M. Ortiz, F. Arocha, M. Medina, X. Gutiérrez, and J.H. Marciano. 2017. Update on standardized catch rates for yellowfin tuna (*Thunnus albacares*) from the Venezuelan pelagic longline fishery of the Caribbean Sea and western central Atlantic. ICCAT-Col. Vol. Sci. Pap., 73:440-450.
- Ortiz, M. and F. Arocha. 2004. Alternative error distribution models for standardization of catch rates of non-target species from a pelagic longline fishery: billfish species in the Venezuelan tuna longline fishery. Fish. Res. 70: 275-297.
- R CORE TEAM. 2015. R: A language and environment for statistical computing. R Foundation for Statistical Computing, Vienna, Austria. URL <http://www.R-project.org/>.

Table 1. Codes for levels of factors included in the analysis of YFT catch rates from the Venezuelan Pelagic Longline.

Season (Quarter)	Category of vessel (CatVes) (Ortiz & Arocha, 2004)	Areas	Bait type (Btype)	Bait condition (Bcond)
Q1: Jan- Mar Q2: April- Jun Q3: Jul- Sep Q4: Oct- Dec	C1: Small vessels (<20 m), operate in Caribbean only, target SWO and tuna, <600 hks/set. C2: Medium vessels (20-26 m), operate in Caribbean and Guyana-Amazon, target tuna and swo, 600-1500 hks/set. C3: Large vessels (26-30 m), operate in Caribbean, SW Sargasso, target tuna, >1500 hks/set.	Area 1:Caribbean Sea Area 2:Guyana-Amazon (Atlantic Ocean) Area 3:SW Sargasso Sea	Bt1: Sardine Bt2: Squid Bt3: Carangid Bt4: Clupeid	Bc0: Unknow Bc1: Live Bc2: Dead

Table 2. Deviance analysis table for explanatory variables in the delta lognormal model for **YFT** catch rates. Percent of total deviance refers to the deviance explained by the full model; *p* value refers to the probability Chi-square test between two nested models. The mean catch rate for positive observations assumed a lognormal error distribution. The highlighted model factors indicate the selected factors for each component of the delta model.

Positives CPUE (LogNormal)					
	Df	Deviance	Residual deviance	<i>p</i>	% of total deviance
NULL			4346.20		0
Year	27	534.95	3811.25	<0.001	23.76
Quart	3	22.71	3788.55	<0.001	1.01
Area	3	378.80	3409.75	<0.001	16.82
Deep	1	33.91	3375.84	<0.001	1.51
CatVess	2	188.79	3187.05	<0.001	8.38
Bcond	1	137.47	3049.58	<0.001	6.11
Btype	3	52.38	2997.21	<0.001	2.33
Year:Quart	76	296.96	2700.24	<0.001	13.19
Year:Area	31	169.28	2530.97	<0.001	7.52
Year:Deep	17	107.28	2423.68	<0.001	4.76
Year:CatVess	28	85.69	2337.99	<0.001	3.81
Year:Bcond	20	33.72	2304.27	<0.001	1.50
Year:Btype	42	117.40	2186.87	<0.001	5.21
Quart:Area	5	1.20	2185.67	0.66	0.05
Quart:Deep	3	14.89	2170.79	<0.001	0.66
Quart:CatVess	6	14.87	2155.92	<0.001	0.66
Quart:Bcond	3	1.91	2154.01	0.16	0.08
Quart:Btype	9	22.75	2131.26	<0.001	1.01
Area:Deep	2	1.32	2129.94	0.17	0.06
Area:CatVess	2	12.14	2117.80	0.00	0.54
Area:Bcond	2	0.74	2117.05	0.37	0.03
Area:Btype	3	3.39	2113.66	0.03	0.15
Deep:CatVess	2	3.38	2110.28	0.01	0.15
Deep:Bcond	1	0.01	2110.27	0.87	0.00
Deep:Btype	3	2.66	2107.61	0.07	0.12
CatVess:Bcond	2	1.24	2106.36	0.19	0.06
CatVess:Btype	5	11.62	2094.75	<0.001	0.52
Bcond:Btype	2	0.21	2094.53	0.75	0.01

Proportion of positives (Binomial)					
	Df	Deviance	Residual deviance	p	% of total deviance
NULL			3614.45		
Year	27	1095.23	2519.22	<0.001	33.50
Quart	3	125.10	2394.13	<0.001	3.83
Area	3	492.96	1901.17	<0.001	15.08
Deep	1	1.10	1900.07	<0.001	0.03
CatVess	2	105.43	1794.63	<0.001	3.23
Bcond	1	41.11	1753.53	<0.001	1.26
Btype	3	148.40	1605.13	<0.001	4.84
Year:Quart	76	293.52	1311.61	<0.001	8.98
Year:Area	31	230.69	1080.92	<0.001	7.06
Year:Deep	17	85.09	995.84	<0.001	2.60
Year:CatVess	29	225.19	770.65	<0.001	6.89
Year:Bcond	20	19.69	750.96	0.48	0.60
Year:Btype	44	202.10	548.85	<0.001	6.18
Quart:Area	5	29.58	519.28	<0.001	0.90
Quart:Deep	3	12.46	506.82	0.01	0.38
Quart:CatVess	6	36.06	470.76	<0.001	1.10
Quart:Bcond	3	4.63	466.13	0.20	0.14
Quart:Btype	9	40.23	425.91	<0.001	1.23
Area:Deep	2	0.41	425.49	0.81	0.01
Area:CatVess	3	4.23	421.26	0.24	0.13
Area:Bcond	2	5.53	415.72	0.06	0.17
Area:Btype	4	7.00	408.72	0.14	0.21
Deep:CatVess	2	12.34	396.38	0.00	0.38
Deep:Bcond	1	19.65	376.72	0.00	0.60
Deep:Btype	3	9.10	367.63	0.03	0.28
CatVess:Bcond	2	3.85	363.78	0.15	0.12
CatVess:Btype	5	5.96	357.82	0.31	0.18
Bcond:Btype	2	12.35	345.47	0.00	0.38

Table 3. Analyses of delta lognormal mixed model formulations for **YFT** catch rates (in numbers). The difference in log-likelihoods was compared with a Chi-squared distribution. The highlighted model indicates the selected model for each component of the delta model.

	Log Likelihood	Akaike's Information Criterion	Bayesian Information Criterion	Likelihood Ratio Test	
				Chi2	p
Positive CPUE					
Year Area Vessel Bcond	-6522.68	13115.36	13349.69		
Year Area CatVess Bcond Year*Quart	-6137.18	12502.37	13265.64	770.99	<0.001
Year Area Vessel Bcond Year*Quart Year*Area	-5940.17	12170.34	13141.16	394.03	<0.001
Year Area Vessel Bcond Year*Season Year*Area Year*Btype	-5731.41	11842.81	13114.93	417.53	<0.001
Proportion of positives					
Year Area Btype	-1157.23	2382.46	2527.48		
Year Area Btype Year*Quart	-974.70	2175.41	2657.39	365.05	<0.001
Year Area Btype Year*Quart Year*Area	-856.60	2001.21	2615.41	236.20	<0.001
Year Area Btype Year*Quart Year*Area Year*CatVess	-729.84	1809.68	2556.11	253.53	<0.001
Year Area Btype Year*Quart Year*Area Year*CatVess Year*Btype	-614.96	1667.92	1765.92	229.76	<0.001

Table 4. Year-quarter of nominal (**CPUE**) and standardized (**CPUE stand**) catch rates (**#fish** /1000 hooks) of YFT caught by the Venezuelan pelagic longline fleet for the period of 1991-2018.

Year	CPUE nominal	CPUE stand	SD	CPUE stand (scaled Index)	%CV	n
1991	8,45	7,17	4,45	1,00	62,01	108
1992	6,36	5,36	2,46	0,75	45,84	269
1993	5,10	4,11	2,04	0,57	49,58	470
1994	4,63	3,82	1,63	0,53	42,54	340
1995	3,14	2,95	2,01	0,41	68,11	483
1996	5,01	4,31	1,87	0,60	43,49	395
1997	3,27	3,58	1,63	0,50	45,57	367
1998	4,78	4,59	2,21	0,64	48,03	457
1999	6,68	6,23	2,21	0,87	35,44	356
2000	4,53	4,15	2,05	0,58	49,37	334
2001	3,97	3,90	2,54	0,54	65,19	280
2002	4,10	4,28	3,07	0,60	71,72	221
2003	4,16	5,13	4,38	0,72	85,37	326
2004	5,80	5,73	5,42	0,80	94,63	332
2005	11,13	9,90	7,53	1,38	76,03	265
2006	7,61	7,14	5,19	1,00	72,68	313
2007	15,14	15,26	4,88	2,13	31,96	98
2008	12,07	11,72	2,76	1,64	23,50	180
2009	11,23	9,84	3,84	1,37	39,06	147
2010	9,43	8,34	2,73	1,16	32,69	230
2011	8,42	8,28	0,95	1,16	11,50	227
2012	8,82	7,89	1,79	1,10	22,68	451
2013	9,62	8,20	2,55	1,14	31,08	231
2014	10,88	9,04	1,53	1,26	16,88	225
2015	12,24	9,46	2,21	1,32	23,31	99
2016	10,51	8,68	1,67	1,21	19,29	168
2017	10,06	8,30	0,51	1,16	6,10	60
2018	9,32	8,18	1,19	1,14	14,52	49

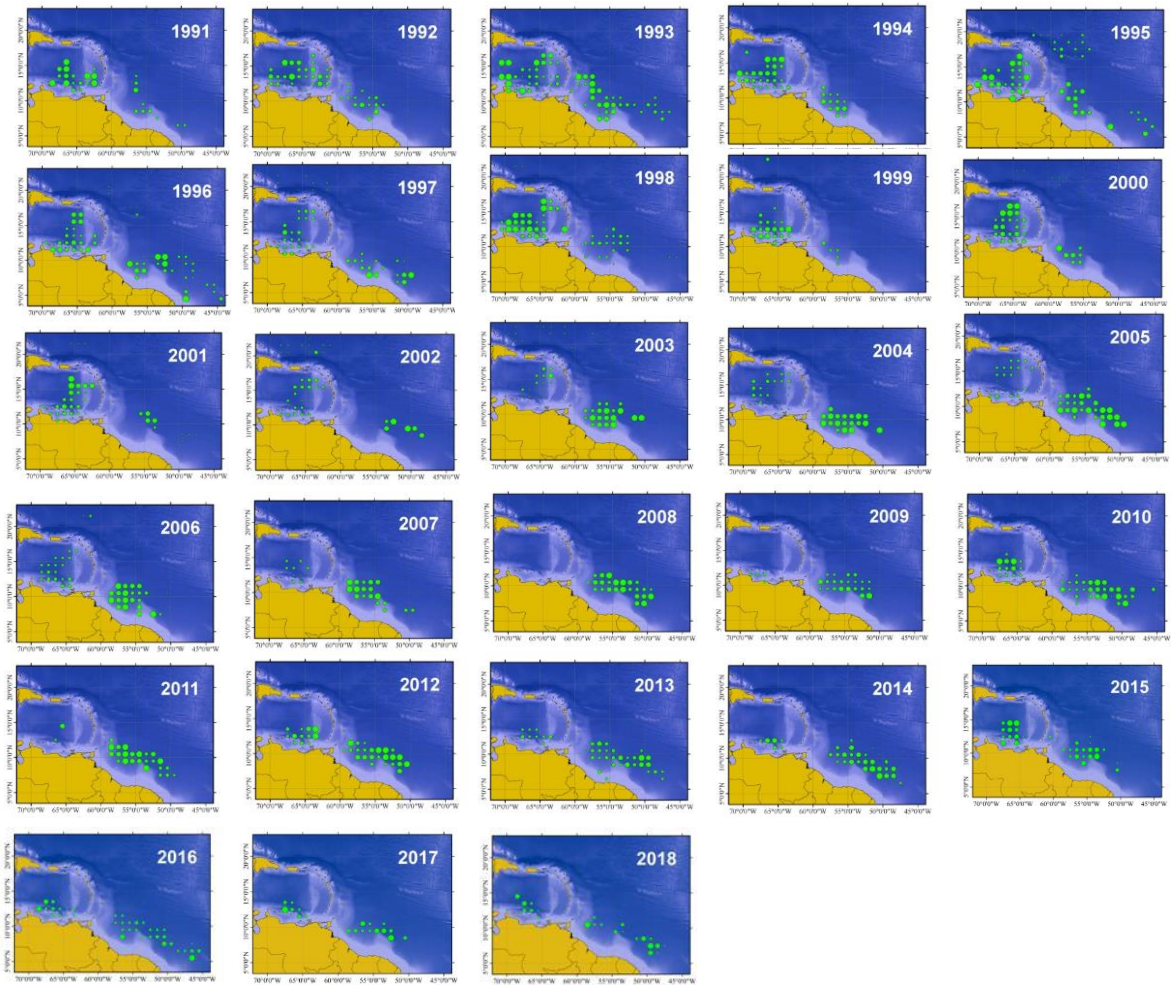


Figure 1. Spatial distribution of nominal CPUE of yellowfin tuna (#fish/1000 hooks) caught by the Venezuelan pelagic longline fleet during 1991-2018 and recorded by VPLOP and PNOB.

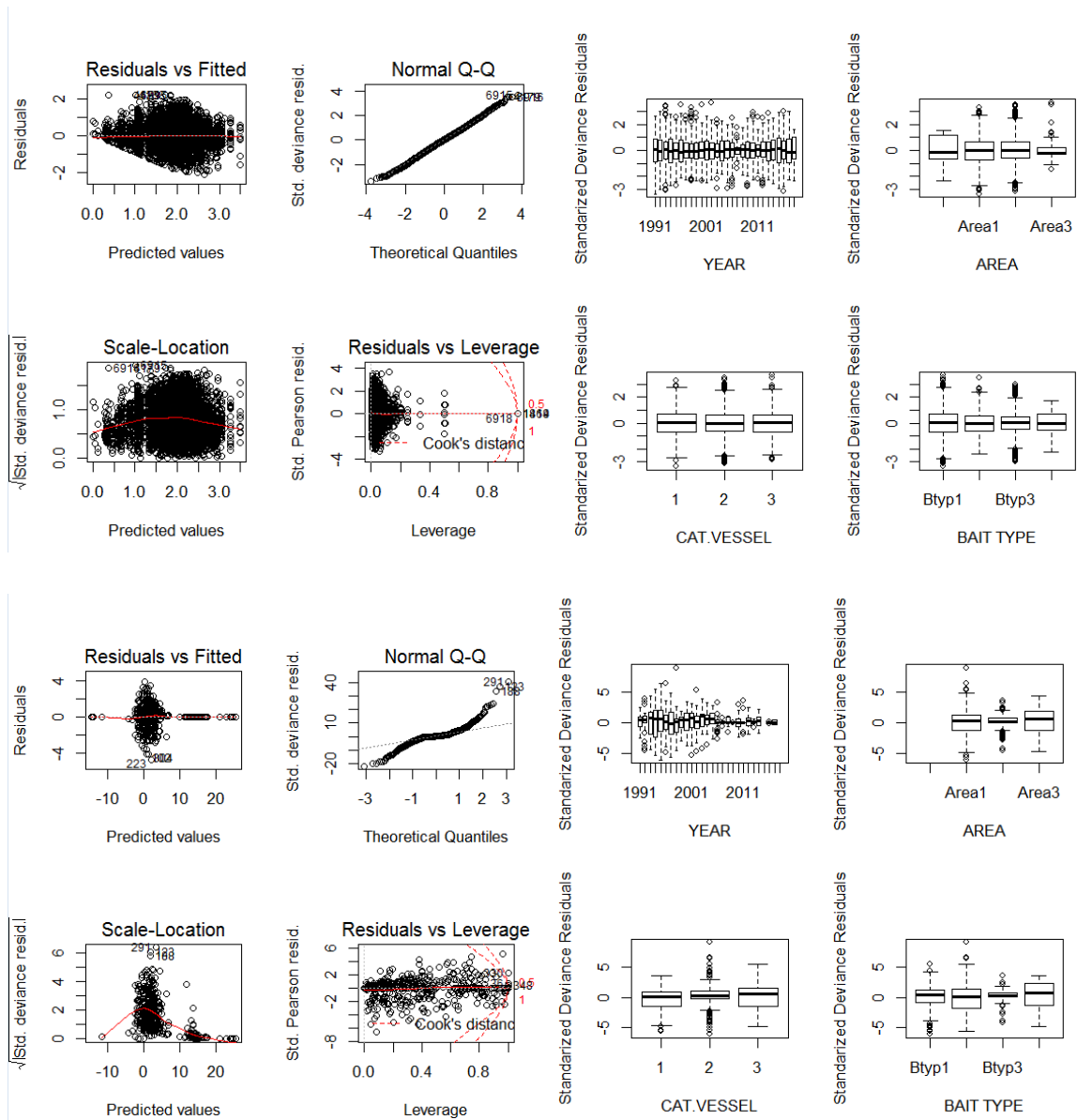


Figure 2. Diagnostic plots for the sub-model of positive catch rates of yellowfin tuna (*T. albacares*) caught by the Venezuelan longline fleet for the period 1991-2018.

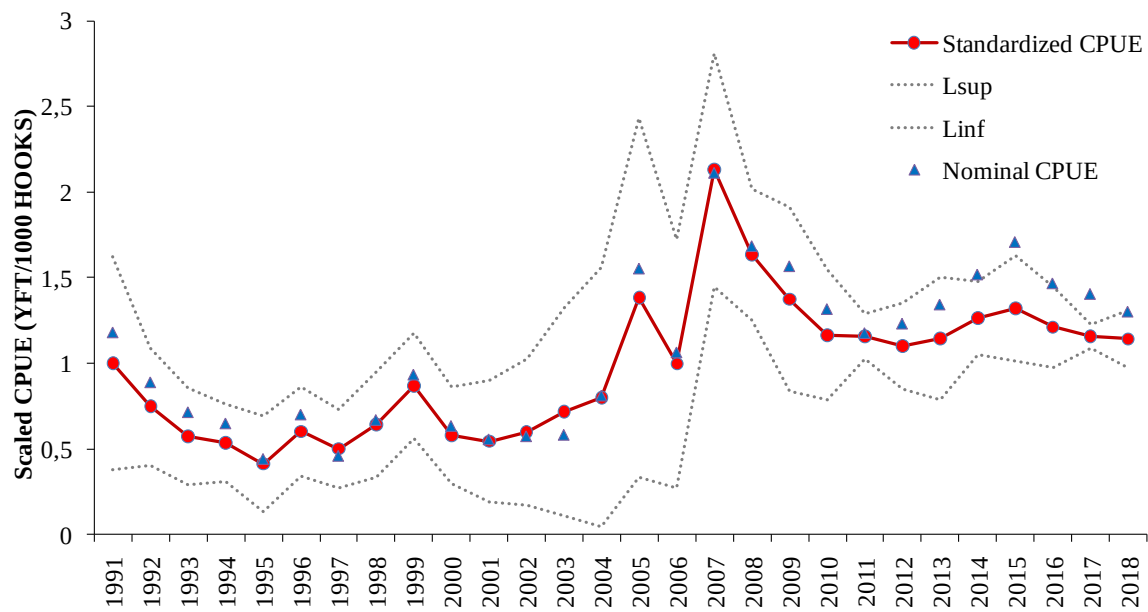


Figure 3. Diagnostic plots for the sub-model proportion of positive catch rates of yellowfin tuna (*T. albacares*) caught by the Venezuelan longline fleet for the period 1991-2018.