STANDARDIZED JOINT CPUE INDEX FOR BLUEFIN TUNA (*THUNNUS THYNNUS*) CAUGHT BY MOROCCAN AND PORTUGUESE TRAPS FOR THE PERIOD 1998-2016

P.G. Lino[1,*], N. Abid[2] , M.I. Mohamed[3], R. Coelho[1]

SUMMARY

*Relative abundance indices of bluefin tuna (*Thunnus thynnus*) caught by the Moroccan and Portuguese traps in the area close to the Strait of Gibraltar were estimated for the period 1998-2016. Data from four Moroccan and one Portuguese tuna traps were compiled and used in the analysis. The trend of the nominal CPUE series shows a relatively low and flat period between 1998 and 2009, followed by a steep increase in the more recent years. Standardized CPUEs were estimated with Generalized Linear Mixed Models (GLMMs) with Negative Binomial distribution, and using the factors year, month and trapID/location. Due to possible changes in the fishery operation patterns since the year when the quotas started to be reached, two separate results are presented: as a single time series and split in 2 periods: 1998-2011 and 2012-2016. In both cases the standardized CPUEs followed in general the nominal CPUE trends, with a relatively low values and a flat period until 2009, followed by increased values for the more recent years.*

RÉSUMÉ

Des indices d'abondance relative de thon rouge (Thunnus thynnus) *capturé par des madragues marocaines et portugaises dans la zone proche du détroit de Gibraltar ont été estimés pour la période allant de 1998 à 2016. Les données de quatre madragues thonières marocaines et d'une madrague thonière portugaise ont été compilées et utilisées dans l'analyse. La tendance de la série de CPUE nominale montre une période relativement faible et plane entre 1998 et 2009, suivie d'une forte augmentation au cours des dernières années. Les CPUE standardisées ont été estimées avec des modèles mixtes linéaires généralisés (GLMM) avec une distribution binomiale négative, et en utilisant les facteurs année, mois et numéro d'identification de la madrague/emplacement. En raison de possibles changements dans les modes d'opération de la pêcherie depuis l'année où les quotas ont commencé à être atteints, deux résultats distincts sont présentés : en tant que série temporelle unique et fractionnée en 2 périodes : 1998-2011 et 2012-2016. Dans les deux cas, les CPUE standardisées ont suivi en général les tendances de la CPUE nominale, avec des valeurs relativement faibles et une période plane jusqu'en 2009, suivie de valeurs beaucoup plus élevées au cours des dernières années.*

RESUMEN

*Se estimaron, para el periodo 1998-2016, índices de abundancia relativa de atún rojo (*Thunnus thynnus*) capturado por almadrabas portuguesas y marroquíes en el área cercana al estrecho de Gibraltar. Se recopilaron los datos de cuatro almadrabas marroquíes y una almadraba portuguesa para utilizarlos en este análisis. La tendencia de la serie de CPUE nominal muestra un periodo relativamente bajo y plano entre 1998 y 2009, al que siguió un aumento marcado en los últimos años. Se estimaron las CPUE estandarizadas con modelos lineales mixtos generalizados (GLMM) con una distribución binomial negativa, y se utilizaron los factores año, mes e ID/ubicación de la almadraba. Debido a posibles cambios en los patrones de las operaciones de pesca desde el año en que empezaron a alcanzarse las cuotas, se presentan dos*

[1] Instituto Português do Mar e da Atmosfera, IPMA I.P., Av. 5 de Outubro s/n, 8700-305 Olhão, Portugal

[2] INRH, Regional Centre of Tangiers, Morocco

[3] Head of fishery department, INRH, central laboratories, Casablanca, Morocco

*Corresponding author: plino@ipma.pt

resultados por separado: para una única serie temporal y desglosados en dos periodos: 1998-2011 y 2012-2016. En ambos casos, las CPUE estandarizadas siguieron en general las tendencias de la CPUE nominal, con valores relativamente bajos y un período plano hasta 2009, seguido valores mucho más altos en los últimos años.

KEYWORDS

Bluefin tuna, CPUE standardization, trap fishery

1. Introduction

Following a BFT WG recommendation, a preliminary standardized CPUE series for the Portuguese trap data was estimated and presented in the 2017 BFT Data Preparatory meeting (Lino *et al.*, 2017).

The relative abundance index of the Moroccan traps has been traditionally used for VPA - calibrating purposes at the Eastern Atlantic Bluefin tunas stock Assessment Sessions (Anonymous, 2015, 2013, 2011, 2009).

Due to the substantial reduction of BFT quota as well as the higher number of fish entering the Moroccan traps, the length of fishing season has been limited to one month since 2012.

As a result of the increasing number of fish passing through the Portuguese South coast waters, since 2012 the quota has been reached. As a result of these changes the Group considered that the trap data for both countries should be analyzed in two separate series: one before 2011 and a second after 2012.

For the 2017 BFT Stock Assessment the Group agreed to include a trap index from the East Atlantic. It was requested that a combined Morocco/Portugal trap index should be calculated and presented to the Group. Therefore the main objective of this document is to address the request and provide a combined Moroccan and Portuguese Trap index for BFT, which can be considered for use in the upcoming BFT stock assessment.

2. Materials and methods

2.1. Data

Data used to calculate and standardize the CPUE was available between 1998 and 2016 for 1 tuna trap off Portugal and 4 tuna traps off Moroccan Atlantic waters (**Figure 1**). The CPUE (response variable) was measured in N BFT per month of operation of the trap (N BFT/Month).

As defined by the BFT working group, the time series were analyzed in 2 separate runs (1998-2011 and 2012-2016) to reflect the possible changes in fishing pattern since the year when the Moroccan quota started to be reached. The Portuguese quota was reached in 2012. Following additional requests from the working group, a model for all the combined years (1986-2016) was also run. It should also be emphasized that the combined data is using only one Portuguese tuna trap (the other 2 traps have only operated for very few years).

2.2. Data analysis

The standardized CPUE series was estimated with Generalized Linear Models (GLMs). The explanatory variables used were year, month and tuna trap ID/location:

- Year: categorical variable, analyzed between 1998 and 2016 (1 single time series 1998-2016 and 2 series: 1998-2011; 2012-2016);
- Month: categorical variable, 1 level for each month. The initial month (1-4) and final months (9-11) were grouped as there was much less data on those months;
- Trap: Categorical variable corresponding to the 5 tuna traps in the analysis (4 tuna traps from Morocco and 1 from Portugal);
- Interactions (without the year factor): tested as fixed factors;

- Interactions (with the year factor): tested as random effects within GLMMs.

The significance of the explanatory variables was assessed with likelihood ratio tests comparing each univariate model to the null model, and by analyzing the deviance explained by each covariate. Goodness-of-fit and model comparison was carried out with the Akaike Information Criteria (AIC). Models we also assessed with residual analysis. Possible interactions not involving the year variable were tested as fixed factors, while interactions between the year and other factors were tested with random effects within GLMM - Generalized Linear Mixed Models.

The distributions tested included the following:

- Poisson
- Negative Binomial
- Tweedie

The final estimated indexes of abundance (standardized CPUEs) were calculated by least square means (LSMeans or Marginal Means). For comparison purposes between models, the standardized CPUEs were scaled by their respective means.

All analysis was carried out using the R Project for Statistical Computing version 3.3.2 (R Core Team, 2016).

3. Results

3.1. Descriptive statistics

There was a small number of fishing months considered in the analysis with BFT catches = 0, specifically only 4.4% of the data, with yearly variations between 0% and 25% (**Figure 2**). The nominal CPUE time series is shown in **Figure 3**. In general the CPUEs were low until 2009, and since then have been increasing for the more recent years.

The nominal BFT CPUE data is over-dispersed (dispersion parameter from Poisson model = 54.4). The distribution is highly skewed to the right due to the presence of a few zeros and most of the values relatively small, but also some very high values (**Figure 4**). Once log transformed the data (positives only) is much more normal shaped (**Figure 4**).

3.2. Variable selection

The 3 main effects (Year, Month and Trap) were significant in the models and used. The interactions between Month and Trap were tested as a fixed factor but could not be included due to the lack of sufficient data on all combinations (i.e., impossibility to calculate model parameters for all combinations). The interaction between Year and Month were significant and used as a random effect within a GLMM framework.

3.3. Model comparison and selection

In terms of model fit and the following is noted:

- Poisson: data is over-dispersed and model fit is poor; there is evidence of over-dispersion in the residuals;
- Tweedie: In general both the model fit and the residuals seem OK.
- Negative Binomial: In general both the model fit and the residuals seem OK, better than the Tweedie.

The residuals of the final tested models (Poisson, Negative Binomial and Tweedie) are shown in **Figure 5**. Overall, the model with the best fit and residuals was the Negative Binomial (**Figure 5**, plots in the bottom) and was therefore selected for the final analysis.

3.4. Final standardized CPUEs (2 split series: 1998-2011; 2012-2016)

On the final models both the year, month and trap factors were significant. The interaction between year and month was also significant and therefore included as a random effect. **Table 1** and **Table 2** show the deviance from the model options using a single time series (1998-2016) or the option with separate models for the 2 time periods (1998-2011 and 2012-2016).

For the model with the single period (1998-2016), the final standardized BFT series is shown in **Figure 6** (scaled by the overall means). The final table with the nominal and standardized series, as well as the CVs and 95% CIs are shown in **Table 3**.

For the model with the 2 separate time periods (1998-2011 and 2012-2016), the final standardized BFT series is shown in **Figure 7** (scaled by each overall means to facilitate the comparisons). The final table with the nominal and standardized series, as well as the CVs and 95% CIs are shown in **Table 4**.

Both standardized CPUE series show low values until 2009 and have been increasing since then. It should also be noted that since 2012 the Portuguese quota has been reached. This means that there is no information on catches per day after the end of quota warning is issued.

Combining with Moroccan trap data has added a spatial factor and reduced the uncertainty in the Moroccan only model.

Acknowledgments

Thanks are due to the TUNIPEX and SEAEXPERT staff and IPMA technicians (T. Simões, J.L. Sofia, L. Reis, S. Goes and R. Lechuga) for collecting the data. Rui Coelho is supported by an Investigador-FCT contract from the Portuguese Foundation for Science and Technology (FCT, Fundação para a Ciência e Tecnologia) supported by the EU European Social Fund and the Programa Operacional Potencial Humano (Ref: IF/00253/2014).

References

Anonymous. 2009. Report of the 2008 Atlantic Bluefin tuna stock assessment session.

Anonymous. 2011. Report of the 2010 Atlantic Bluefin tuna stock assessment session.

Anonymous. 2013. Report of the 2012 Atlantic Bluefin tuna stock assessment session.

Anonymous. 2015. Report of the 2014 Atlantic Bluefin tuna stock assessment session.

Lino, P.G., Rosa, D. & Coelho, R. 2017. Update on the bluefin tuna catches from the tuna trap fishery off southern Portugal (NE Atlantic) between 1998 and 2016 with a preliminary CPUE standardization. SCRS/2017/030: 13p.

R Core Team. 2016. R: A language and environment for statistical computing. R Foundation for Statistical Computing, Vienna, Austria. URL http://www.R-project.org/.

Table 1. Deviance tables of the parameters used for the BFT CPUE standardization models for Portuguese and Moroccan tuna traps (single model for the entire time series: 1998-2016), using a GLMM Negative Binomial with link=log. For each parameter it is indicated the degrees of freedom (Df), the Chisq-test statistic and the significance (p-value).

```
Analysis of Deviance Table (Type II tests)

Response: BFT
           Df  Chisq Pr(>Chisq)
Year       18 60.175  1.917e-06 ***
Month2      5 48.111  3.370e-09 ***
Trap        4 12.960    0.01147 *
Residuals 176
---
Signif. codes:  0 ‘***’ 0.001 ‘**’ 0.01 ‘*’ 0.05 ‘.’ 0.1 ‘ ’ 1
```

Table 2. Deviance tables of the parameters used for the BFT CPUE standardization models for Portuguese and Moroccan tuna traps (separate models for the 2 time series: 1998-2011 in the top table and 2012-2016 in the bottom table), using a GLMM Negative Binomial with link=log. For each parameter it is indicated the degrees of freedom (Df), the Chisq-test statistic and the significance (p-value).

```
Analysis of Deviance Table (Type II tests)

Response: BFT
           Df   Chisq Pr(>Chisq)
Year       13 23.2621    0.03864 *
Month2      5 36.2424  8.495e-07 ***
Trap        4  9.0645    0.05951 .
Residuals 147
---
Signif. codes:  0 ‘***’ 0.001 ‘**’ 0.01 ‘*’ 0.05 ‘.’ 0.1 ‘ ’ 1
```

```
Analysis of Deviance Table (Type II tests)

Response: BFT
           Df    Chisq Pr(>Chisq)
Year        4   8.2552    0.08266 .
Month2      3 170.9720  < 2.2e-16 ***
Trap        4  51.9286  1.428e-10 ***
Residuals 20
---
Signif. codes:  0 ‘***’ 0.001 ‘**’ 0.01 ‘*’ 0.05 ‘.’ 0.1 ‘ ’ 1
```

Table 3: Final standardized CPUE series for BFT (N/month) captured by the Portuguese and Moroccan tuna traps using a GLMM Negative Binomial. Both the CVs and 95% CIs are indicated. This table shows the option for the single time series (1 single model: 1998-2016).

Year	*Nominal CPUE*	*Standardized CPUE index*			
		Stdz CPUE	*Lower CI (95%)*	*Upper CI (95%)*	*CV (%)*
1998	31.00	19.66	8.28	46.67	48.5
1999	12.60	10.43	2.91	37.43	62.9
2000	34.40	19.22	5.30	69.71	63.5
2001	25.44	18.30	5.02	66.76	80.6
2002	19.76	14.39	4.02	51.44	81.8
2003	14.72	7.36	2.08	26.08	83.6
2004	11.25	6.90	2.07	23.04	75.1
2005	19.14	16.61	4.69	58.84	73.7
2006	33.64	21.10	6.00	74.17	64.9
2007	25.92	28.86	7.99	104.20	69.3
2008	14.70	9.70	2.59	36.28	65.0
2009	25.78	17.56	4.65	66.30	62.1
2010	97.57	34.30	9.07	129.61	54.8
2011	144.00	49.69	12.74	193.87	63.6
2012	189.14	68.18	17.91	259.58	55.1
2013	231.86	113.24	27.17	471.94	58.8
2014	198.50	84.87	21.30	338.22	52.8
2015	242.71	114.86	29.39	448.87	56.2
2016	310.71	91.76	23.95	351.59	55.4

Table 4. Final standardized CPUE series for BFT (N/month) captured by the Portuguese and Moroccan tuna traps using a GLMM Negative Binomial. Both the CVs and 95% CIs are indicated. This table shows the option for the time series split into two separate models (2 separate models: 1998-2011 and 2012-2016).

Year	*Nominal CPUE*	*Standardized CPUE index*			
		Stdz CPUE	*Lower CI (95%)*	*Upper CI (95%)*	*CV (%)*
1998	31.00	19.91	8.39	47.25	55.64
1999	12.60	10.28	2.99	35.34	69.78
2000	34.40	19.65	5.54	69.72	71.53
2001	25.44	18.69	5.21	67.01	91.24
2002	19.76	14.61	4.16	51.32	92.51
2003	14.72	7.68	2.17	27.20	95.82
2004	11.25	6.91	2.15	22.20	83.36
2005	19.14	16.51	4.84	56.36	82.06
2006	33.64	22.47	6.39	78.99	74.47
2007	25.92	29.24	8.32	102.76	77.77
2008	14.70	10.26	2.85	36.94	72.37
2009	25.78	16.44	4.57	59.12	68.59
2010	97.57	36.82	10.21	132.81	60.63
2011	144.00	59.28	14.12	248.88	76.88
2012	189.14	41.15	9.31	181.89	49.06
2013	231.86	88.58	17.07	459.72	54.36
2014	198.50	48.54	9.52	247.42	49.78
2015	242.71	66.98	13.07	343.32	53.94
2016	310.71	64.03	12.69	323.10	53.43

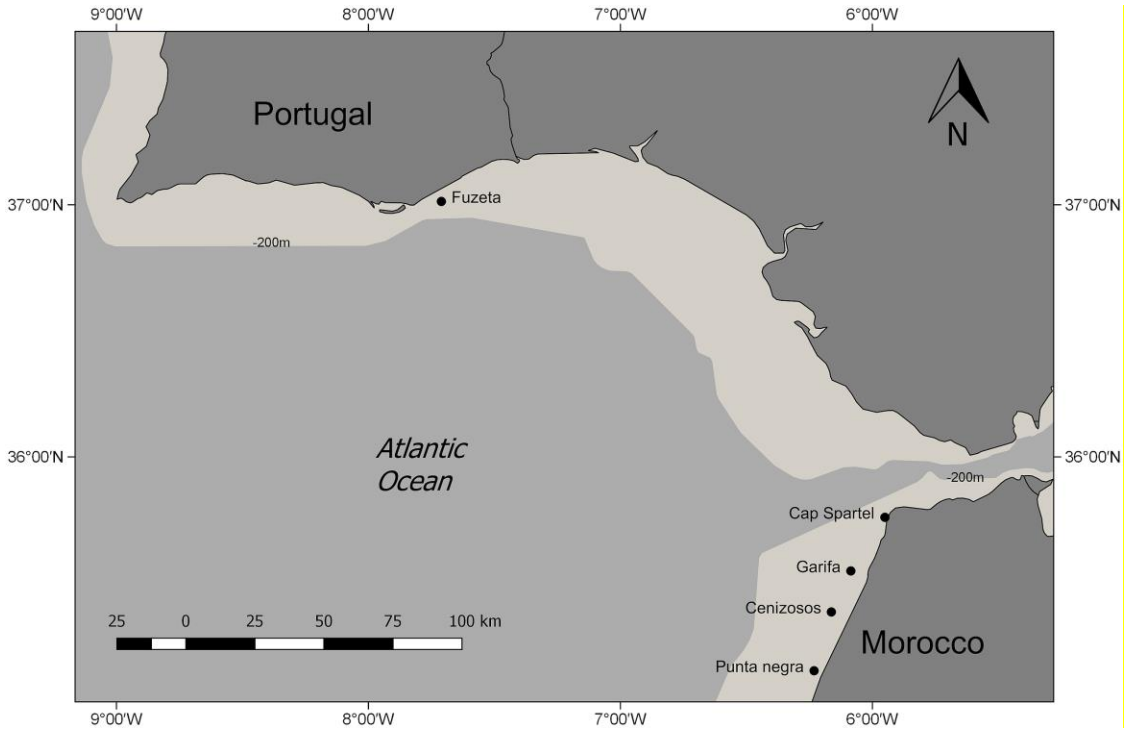

Figure 1. Location of the tuna traps off the South coast of Portugal and the Atlantic coast of Morocco used for the CPUE standardization.

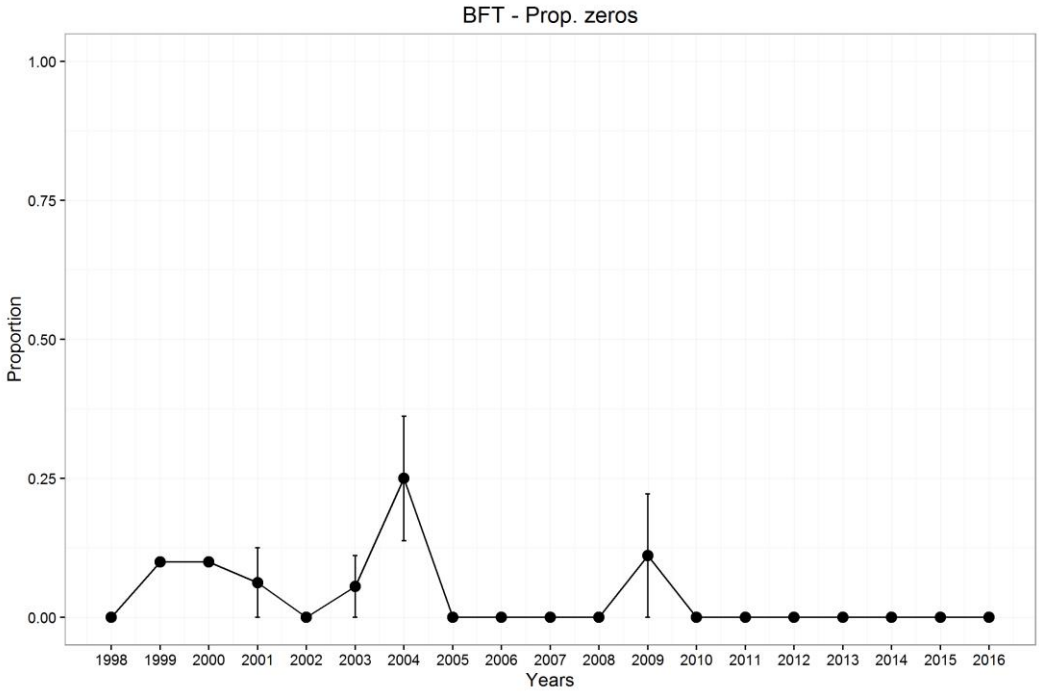

Figure 2. Proportion of months (effort) with 0 BFT catches during the tuna traps operation season, between 1998 and 2016. The error bars refer to the standard errors. The overall mean percentage of zeros in the datasets is 4.4%.

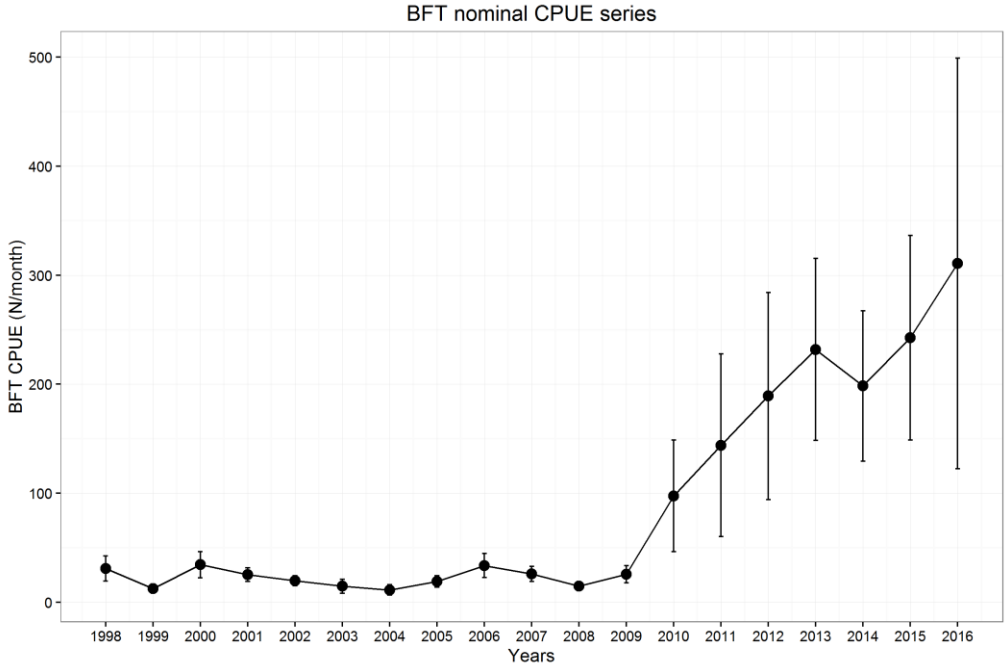

Figure 3. Nominal CPUE series (N/month) for BFT caught in the tuna traps off Portugal and Morocco, between 1998 and 2016. The error bars refer to the standard errors.

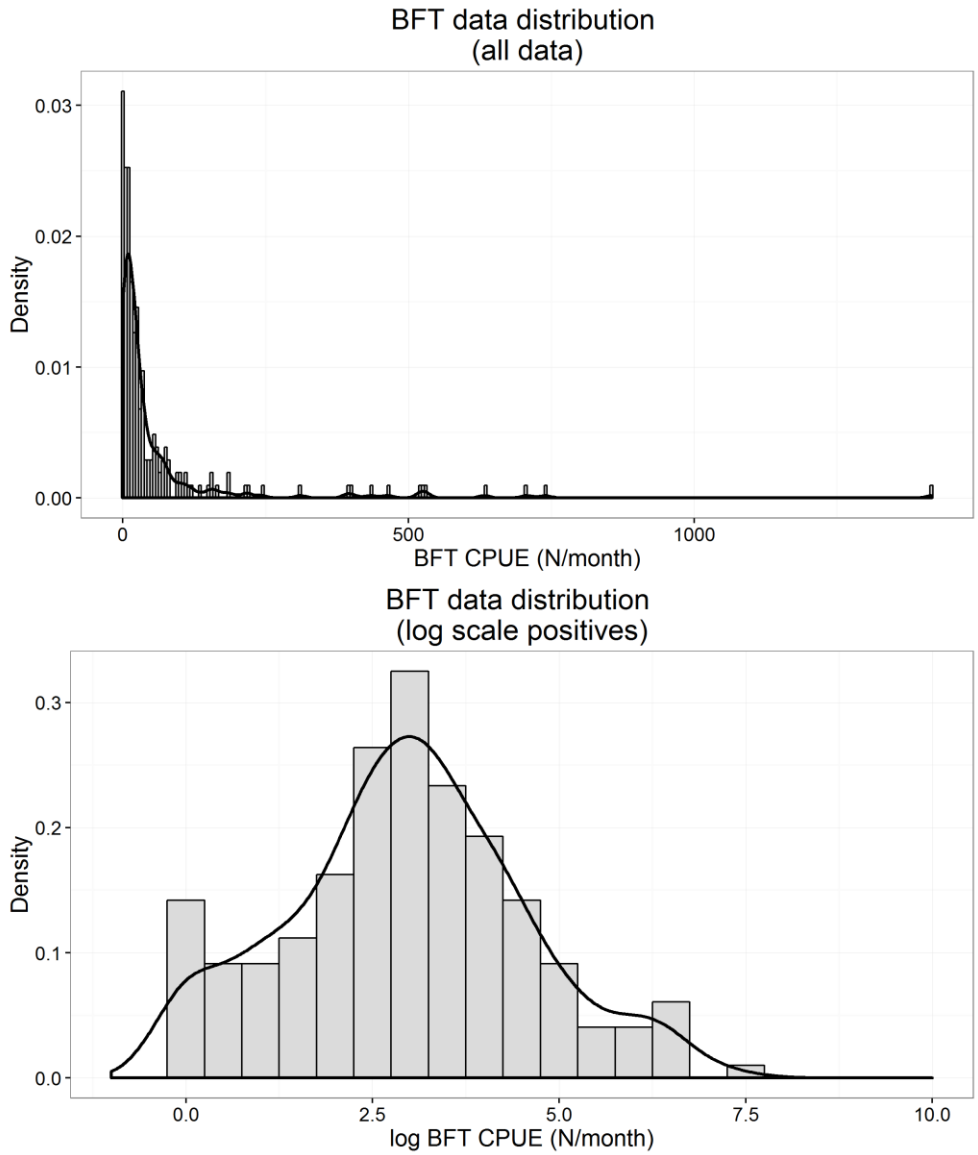

Figure 4. Distribution of the nominal BFT CPUE (N/month) captured by the Portuguese and Moroccan tuna traps. The plot on the top represents all data available and the plot in the bottom represents the data in log-scale (positives only).

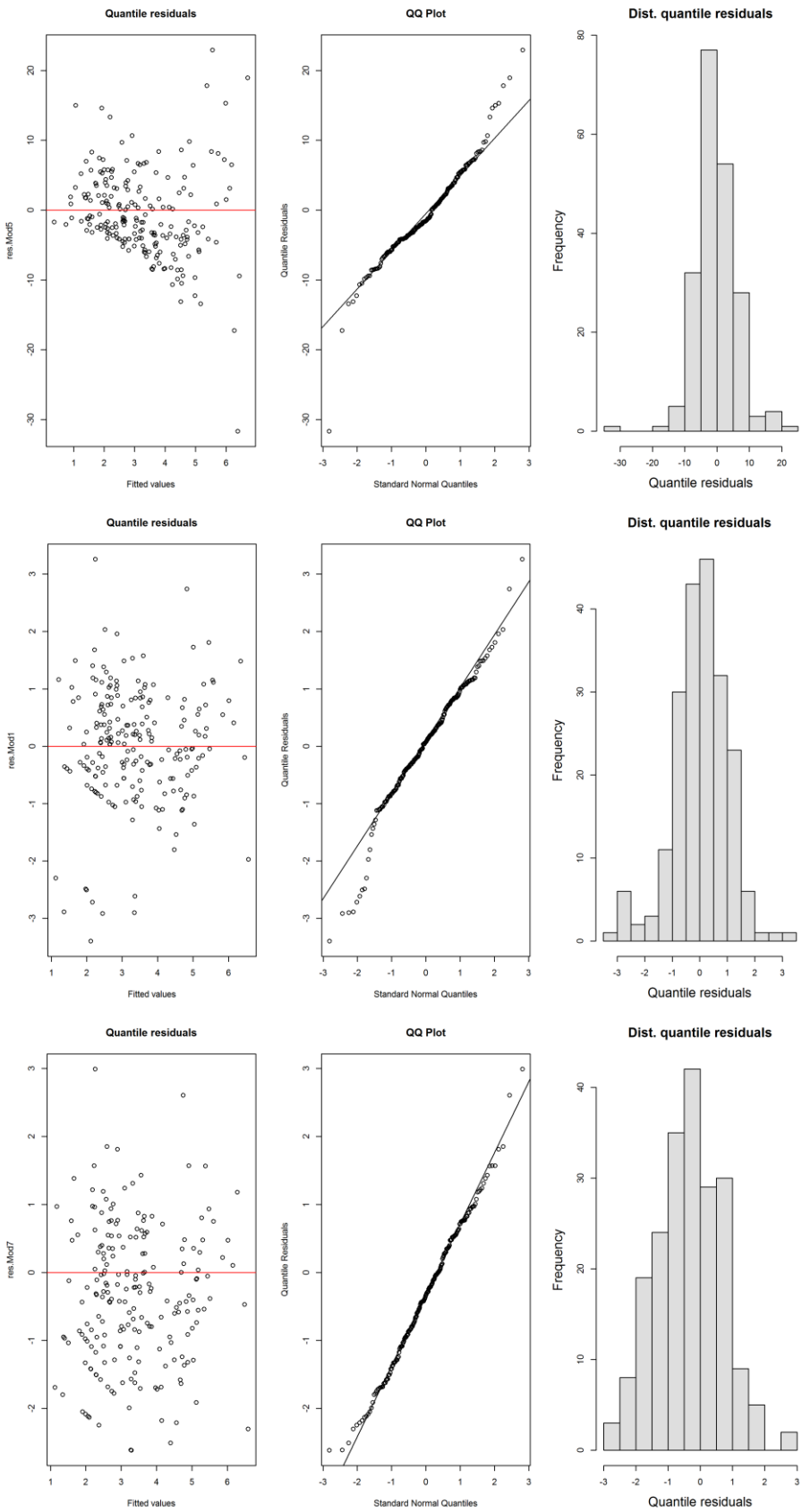

Figure 5: Residual analysis for the various candidate models for the BFT CPUE standardization in the tuna traps off Portugal and Morocco. On top the residuals from the Poisson, in the middle from the Tweedie and in the bottom from the Negative Binomial. The plots represent the residuals along the fitted values (left), the QQPlot (middle) and the histogram of the distribution of the residuals (right). The final selected model was the Negative Binomial.

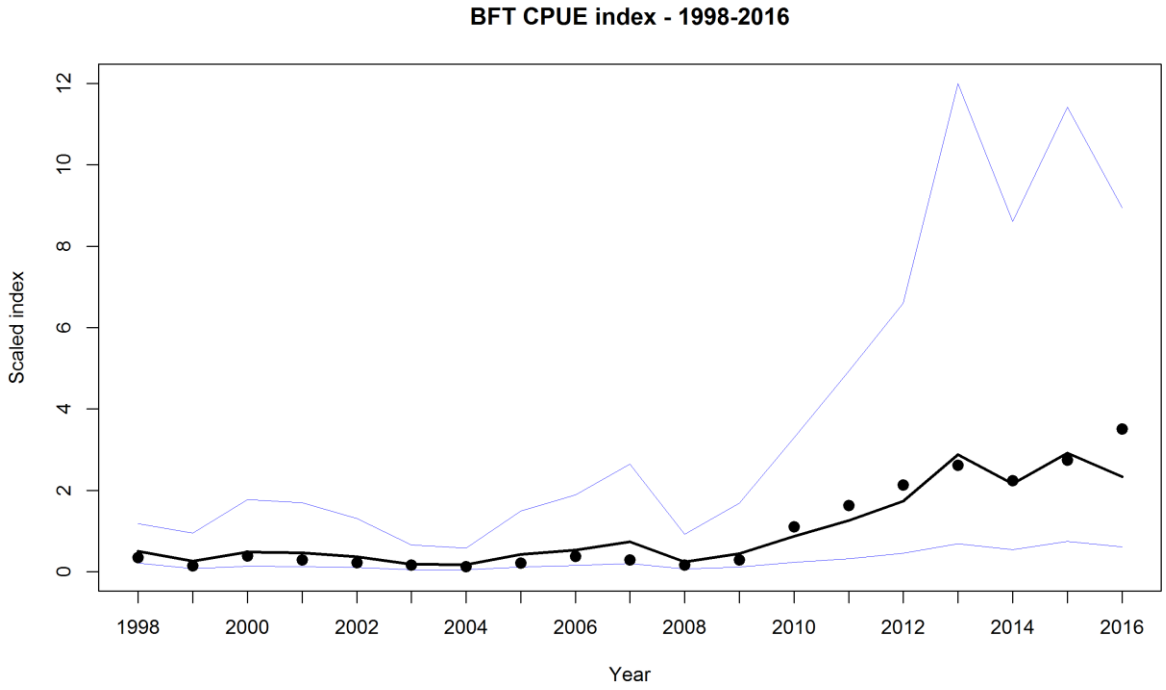

Figure 6. Standardized CPUE series for BFT captured by the Portuguese and Moroccan tuna traps using a GLMM Negative Binomial for all years (1986-2016). The light blue lines are the 95% confidence intervals of the standardized series and the nominal series is represented in the black dots. For comparison purposes both the standardized and nominal CPUEs were scaled by their respective means.

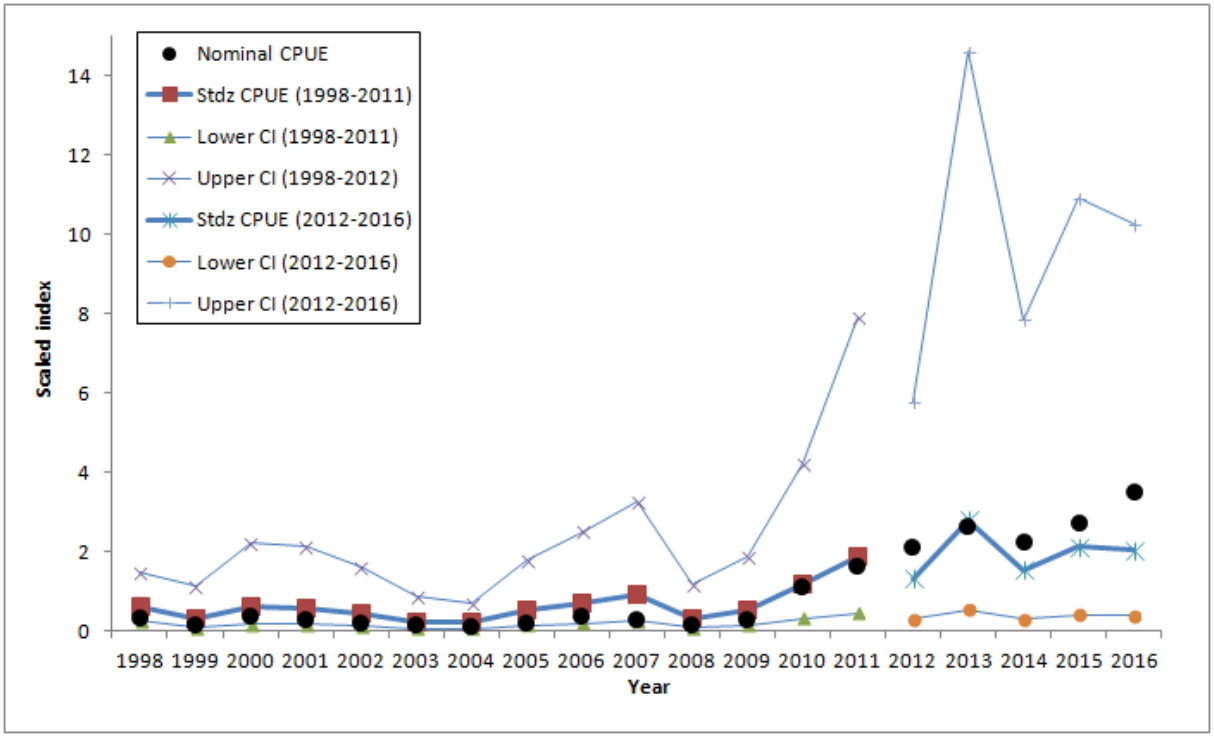

Figure 7. Standardized CPUE series for BFT captured by the Portuguese and Moroccan tuna traps using a GLMM Negative Binomial. Separate models for the 2 time series (1986-2011 and 2012-2016) were run. The light blue lines are the 95% confidence intervals of the standardized series and the nominal series is represented in the black dots. For comparison purposes both the standardized and nominal CPUEs were scaled by their respective means.