Standardized CPUE of blue shark caught by the French swordfish fishery in the south-west Indian Ocean (2007-2016)

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ABSTRACT. The blue shark *Prionace glauca* is the main bycatch of the French swordfish-targeting longline fishery operating in the south-west Indian Ocean. Using observer and self-reported data collected aboard commercial longliners between 2007 and 2016, we propose for the first time a standardized CPUE series for blue shark for this fishery estimated with a lognormal generalized linear mixed model (GLMM) to be used for stack assessment.

KEYWORDS. Blue shark | CPUE standardization | Longline | Western Indian Ocean

1. Introduction

Primary indices of abundance of target species (e.g. tunas) and non-target species (e.g. sharks) are based on catch and effort data from commercial fisheries in the absence of fishery-independent abundance indices. Fishery-based indices need to be standardized in order to remove the influence of factors such as the effort, targeting, etc., so they can be used for stock assessment (Maunder and Punt, 2004).

The French longline fishery based in Reunion Island operating the south-west Indian Ocean mainly targets swordfish with night sets. The blue shark *Prionace glauca* is the main bycatch species and represents 37% of the bycatch in number of individuals caught (Sabarros et al., 2013).

For the first time, we provide an index of abundance for the blue shark based on observer data in the French swordfish fishery based in Reunion Island for the period 2007-2016.

2. Material and methods

2.1. Data

We used data collected by sea-going observers on French longline vessels (Bach et al., 2008) as well as data collected by fishermen themselves called “self-reported data” (Bach et al., 2013). Data were collected through CAPPER (2007-2008) and EU Data Collection Framework (2009-2016; Reg 199/2008 and 665/2008). The coverage in number of hooks observed is presented in Figure 1. We retained a total of 2375 fishing operations monitored between 2007 and 2016 from the core fishing area which consists of 5°x5° squares were more than 50 fishing operations were observed (Figure 2).

2.2. CPUE standardization

The response variable considered was the catch per unit of effort (CPUE) in number of individuals per 1000 hooks deployed. The proportion of zeros was 11% with a CPUE distribution skewed towards the left (Figure 3). We added a constant (c = 1) and log-transformed the CPUE, and the log(CPUE+1) now exhibits a Gaussian shape (Figure 3).

We estimated the standardized CPUE with lognormal Generalized Linear Mixed Models (GLMM) using *glmer* function from *lme4* R package (Bates et al., 2017). According to the distribution of log(CPUE+1), we chose a Gaussian distribution for the residuals (link function: identity).

We first fitted a full model (Mod 0; Table 1) with a list of covariates that were identified in a previous work on the characterisation of blue shark hotspots in the south-west Indian Ocean (Selles et al., 2014):

- Fixed effects:
    - year: 2007 to 2016
    - quarter: Q1 to Q4

  - region: west and east of 52°E, it roughly corresponds to the EEZ of Madagascar and Reunion Island respectively.
  - quarter:region: interaction between quarter and region.
  - cwp55: FAO's CWP (Coordinating Working Party on Fishery Statistics) reference 5°x5° squares identifiers (www.fao.org/fishery/cwp).
  - soakingtime: time in hours from when the first hook is deployed to when the last hook retrieved.
  - settingstarttime: time in the afternoon (hh:mm) when the first hook is deployed.
  - haulingstarttime: time in the morning (hh:mm) when the first hook is retrieved.
  - meanfloatlinelength: average length in meters of floatlines as a relative index of fishing depth.
  - hooksperbasket: number of hooks per basket, also a relative index of fishing depth.
  - percentagecirclehooks: relative proportion of circle hooks to other types of hooks (J-hooks, tuna hooks, Teracima hooks).
  - percentagesquidbait: proportion of squid bait relatively to other bait used (mackerel, etc.).
- Random effects:
  - vessel: the vessel name was used to account for various effects linked to the Captain strategy or boat characteristics.

Mod 0: year + quarter + region + quarter:region + cwp55 + soakingtime + settingstarttime + haulingstarttime + meanfloatlinelength + hooksperbasket + percentagecirclehooks + percentagesquidbait + (1 | vessel)

We then ran a backward-stepwise model selection using the *step* function in *lsmeans* R package (Lenth, 2017) to select for relevant and significant covariates. The deviance table (ANOVA type II) is provided in Table 1, the summary table is Table 2, and the graphical residual analysis is presented in Figure 4.

Finally, we present the yearly standardized CPUE series from the retained model computed using the *lsmeans* function from *lsmeans* R package (Length, 2017; Table 3; Figure 5).

3. Results

The model selection procedure based on the AIC score selected a lognormal GLMM with fewer covariates (Mod 1) than the full model Mod 0 (Tables 1 and 2):

Mod 1: year + quarter + region + quarter:region + cwp55 + soakingtime + haulingstarttime + hooksperbasket + percentagecirclehooks + (1 | vessel)

4. Discussion

Significant effects on blue shark CPUE

The year, quarter, region (west and east of 52°E, roughly corresponding to the EEZ of Madagascar and Reunion Island respectively) as well as 5°x5° squares (cwp55) have a significant effect on blue shark catch rates. This is also the case for the interaction between the quarter and region which was originally implemented to account for the fact that the fishing effort is concentrated in the Malagasy EEZ in the 2nd quarter and mostly 3rd for vessels above 12 meters (length overall) that can reach that far, while most vessels stay in the Reunion Island EEZ during the 4th and 1st quarters of the year (Sabarros et al., 2013). We can note that blue shark catch rate is particularly high for vessels that remained in Reunion Island EEZ during the 3rd quarter (Table 2).

The overall soaking time and time when the line is hauled have a positive effect on blue shark bycatch rate as previously demonstrated (Auger et al., 2015). Indeed, longer the line stays in the water and later is it hauled, more bycatch and notably blue sharks will be caught.

The number of hooks per basket is a proxy of fishing depth and displays a positive effect suggesting blue shark CPUE increases with fishing depth. In Reunion Island longline fishery, hooks are generally set between 10 meters from the surface down to 120 meters (Bach et al., 2014).

The percentage of circle hooks tends to slightly increase blue shark captures as demonstrated in the Australian (Ward et al., 2009) and Taiwanese longline fisheries (Huang et al., 2015).

Relevance of the final standardized CPUE series

The data considered in this standardization work only concern the core fishing area illustrated in Figure 2. This was a safer approach than considering the total dataset that includes scarce sets located in the Mozambique Channel etc. that might exhibit different patterns in terms of blue shark catch rates than those in the core fishing area. A sensitivity analysis would help answer that question.

The residual analysis of the retained lognormal GLMM (Mod 1; Figure 3) used to standardized blue shark CPUE did not exhibit violation of normality nor heteroscedasticity which suggests that the log transformation of the CPUE and distribution chosen (Gaussian with identity link) in the model are satisfactory.

Despite the selection of a model with fewer covariates (Mod 1), the resulting standardized CPUE series of Mod 0 and Mod 1 are very similar (Figures 4 and 5). Compared to the nominal CPUE series, the final standardized CPUE series is smoother but still shows variations over time.

Considering the relatively low coverage rate in number of hooks observed in the first years of implementation of the observation program under CAPPER (< 1%), we should consider discarding the early part of the standardized time series, at least the first year. The final time series would span from 2008 to 2016.

5. Conclusion

According to the assessment of the retained standardization model, we believe that the standardized CPUE time series we propose for blue shark caught by the French longline fishery in the south-west Indian Ocean is reliable and can be used for stock assessment, at least when considering the period 2008-2016. This 9-years time series is the first provided by France for blue shark.

6. Acknowledgments

We thank the observers and Captains that collected data through CAPPER and EU DCF data collection programs.

7. References

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8. Tables

Table 1. Deviance table (ANOVA type II) of the covariates in lognormal GLMM Mod 0 (full model) and Mod 1 (retained model). For each covariate, we indicate the degrees of freedom (Df), the sum of squares (Sum Sq), the mean squares (Mean Sq), the F test statistic (F value) and the significance (P value).

Models	Covariates	Df	Sum Sq	Mean Sq	F value	P value
Mod 0: full model Lognormal GLMM Random effect: vessel N = 2375 R2 = 0.3585 AIC = 4543	year	9	17,42	1,94	5,51	
	quarter	3	18,75	6,25	17,78	
	region	1	7,62	7,62	21,68	
	cwp55	6	14,45	2,41	6,85	
	soakingtime	1	2,73	2,73	7,76	
	settingstarttime	1	0,01	0,01	0,03	
	haulingstarttime	1	2,1	2,1	5,98	
	meanfloatlinelength	1	0,14	0,14	0,41	
	hooksperbasket	1	6,24	6,24	17,77	
	percentagecirclehooks	1	2,84	2,84	8,09	
	percentagesquidbait	1	0,68	0,68	1,93	
	quarter:region	3	6,86	2,29	6,5	
Mod 1: selected model Lognormal GLMM Random effect: vessel N = 2375 R2 = 0.3572 AIC = 4511	year	9	17,42	1,94	5,51	< 0.001
	quarter	3	18,75	6,25	17,78	< 0.001
	region	1	7,62	7,62	21,68	< 0.001
	cwp55	6	14,46	2,41	6,85	< 0.001
	soakingtime	1	2,72	2,72	7,75	< 0.001
	haulingstarttime	1	1,93	1,93	5,48	< 0.001
	percentagecirclehooks	1	2,74	2,74	7,78	< 0.001
	hooksperbasket	1	6,35	6,35	18,05	< 0.001
	quarter:region	3	6,55	2,18	6,21	< 0.001

Table 2. Summary table of standardization lognormal GLMM Mod1.

```
Linear mixed model fit by REML ['lmerMod']
Formula: logcpue ~ year + quarter + region + quarter:region + cwp55 +
    soakingtime + haulingstarttime + percentagecirclehooks +
    branchlinesperbasketcount + (1 | vessel)
   Data: catch.bsh

REML criterion at convergence: 4452.7

Scaled residuals:
    Min      1Q  Median      3Q     Max
-2.9506 -0.5871  0.0693  0.6614  3.5768

Random effects:
 Groups   Name        Variance Std.Dev.
 vessel   (Intercept) 0.1556   0.3944
 Residual             0.3516   0.5930
Number of obs: 2375, groups:  vessel, 37

Fixed effects:
                        Estimate Std. Error t value
(Intercept)            0.5837369  0.2488633   2.346
year2008              -0.5343401  0.2251462  -2.373
year2009              -0.5496605  0.2398981  -2.291
year2010              -0.0923607  0.2391709  -0.386
year2011              -0.3187694  0.1844508  -1.728
year2012              -0.2835892  0.1769734  -1.602
year2013              -0.4440673  0.1772201  -2.506
year2014              -0.4938053  0.1786814  -2.764
year2015              -0.4921916  0.1782710  -2.761
year2016              -0.4156552  0.1812909  -2.293
quarterQ2             -0.0880889  0.0576062  -1.529
quarterQ3             -0.1636686  0.0557622  -2.935
quarterQ4              0.1152343  0.0758927   1.518
regionREU              0.1643346  0.0681534   2.411
cwp55215050           -0.0031053  0.0765335  -0.041
cwp55215055           -0.4437019  0.1085210  -4.089
cwp55220045           -0.0276062  0.0687850  -0.401
cwp55220050           -0.0010196  0.0710500  -0.014
cwp55220055           -0.0745868  0.0818592  -0.911
cwp55225045            0.2704538  0.1087004   2.488
soakingtime            0.0103331  0.0049449   2.090
haulingstarttime       0.0330056  0.0167935   1.965
percentagecirclehooks  0.0021384  0.0007662   2.791
hooksperbasket         0.0653128  0.0163443   3.996
quarterQ2:regionREU   -0.0004669  0.0886786  -0.005
quarterQ3:regionREU    0.2505357  0.0826854   3.030
quarterQ4:regionREU   -0.0815374  0.0894204  -0.912
```

Table 3. Standardized CPUE (stdCPUE) time series for blue shark caught in the French longline fishery for the period 2007-2016. nCPUE designates the original nominal CPUE. The stdCPUE is provided with 95% confidence interval (CI).

Year	nCPUE	stdCPUE	Lower CI	Upper CI
2007	1,97	**3,79**	2,36	5,83
2008	1,95	**1,81**	1,02	2,91
2009	2,47	**1,77**	0,96	2,9
2010	4,79	**3,37**	2,14	5,07
2011	2,96	**2,48**	1,91	3,18
2012	3,35	**2,61**	2,08	3,23
2013	2,68	**2,07**	1,63	2,6
2014	2,46	**1,92**	1,49	2,43
2015	2,5	**1,93**	1,5	2,44
2016	3,02	**2,16**	1,68	2,73

9. Figures

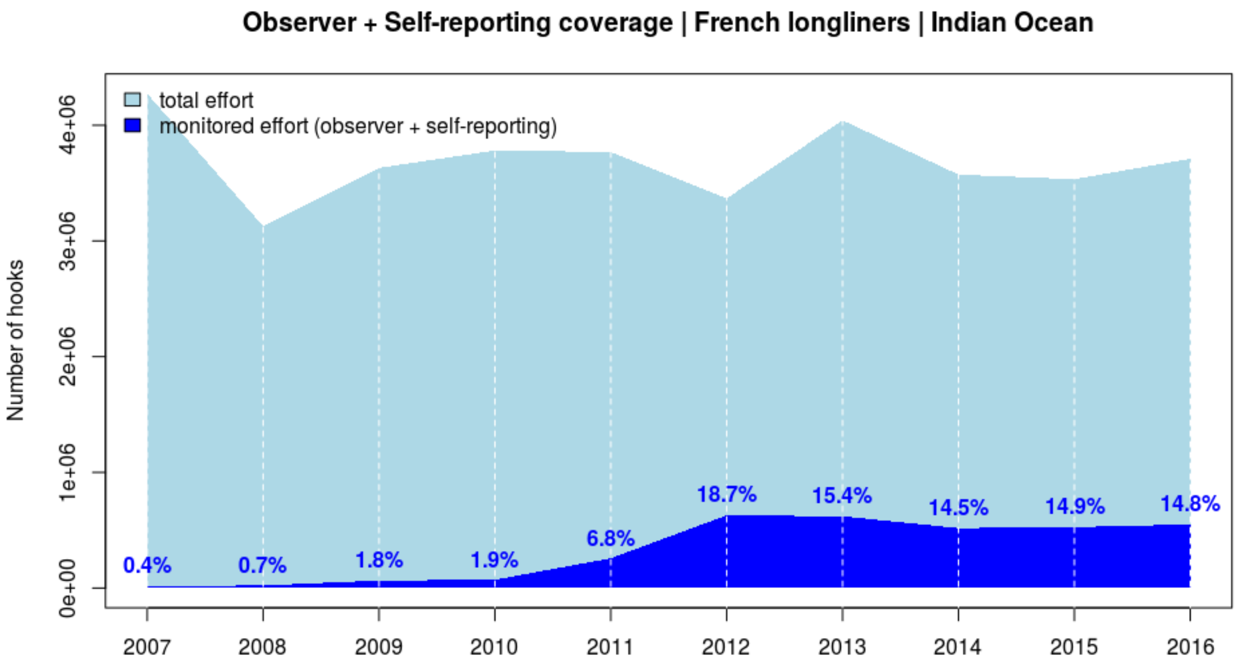

Figure 1. Observer and self-reporting effort coverage in number of hooks deployed in the French longline fishery operating in the south-west Indian Ocean between 2007 and 2016.

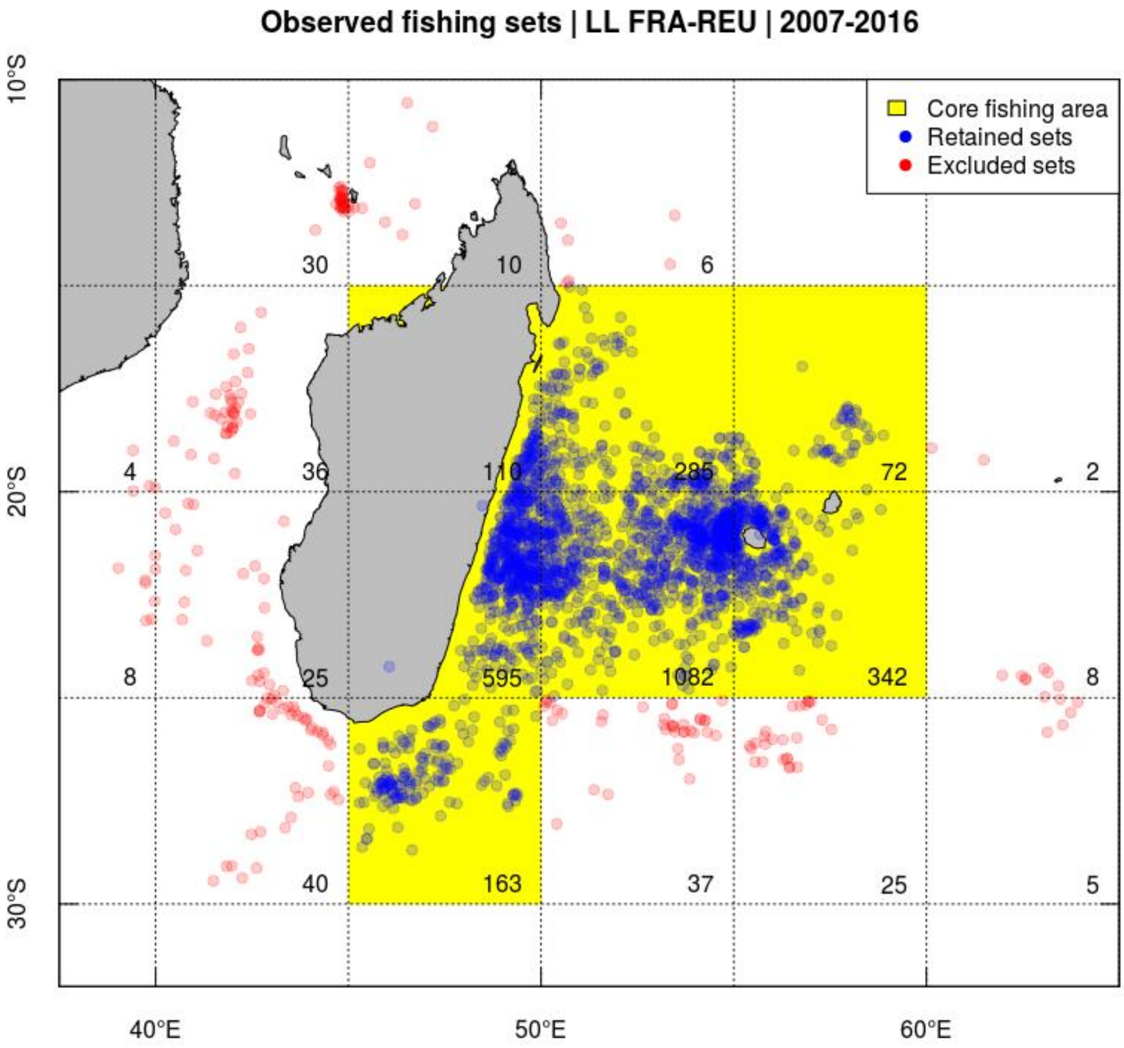

Figure 2. Distribution of fishing sets (hauling start position) between 2007 and 2016. The yellow area represents the core fishing area with retained sets in blue. Excluded sets are shown in red. Numbers in the corners of 5°x5° squares are the number of sets.

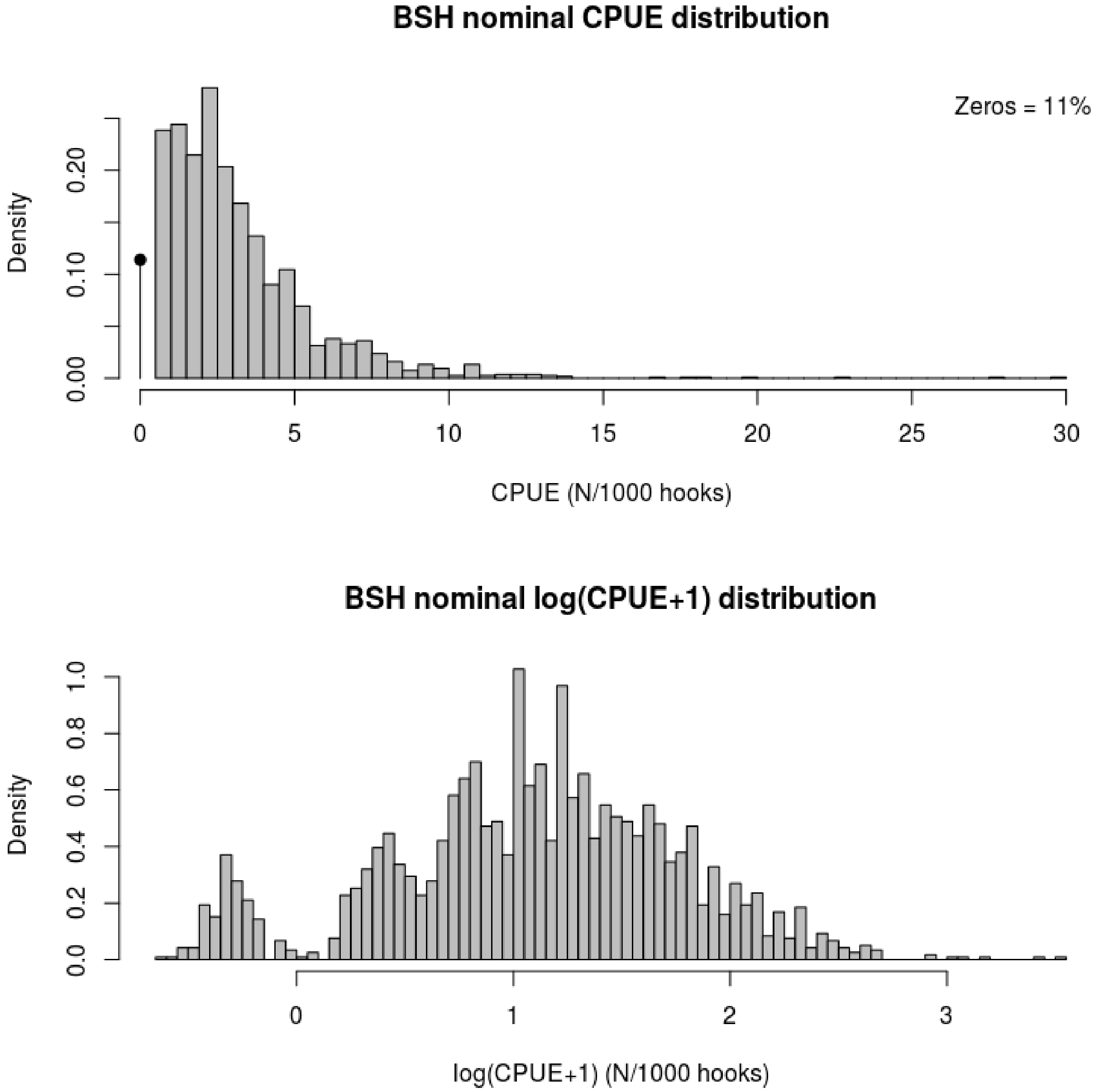

Figure 3. Blue shark nominal CPUE (N/1000 hooks; top panel) and log(CPUE+1) (bottom panel) distributions.

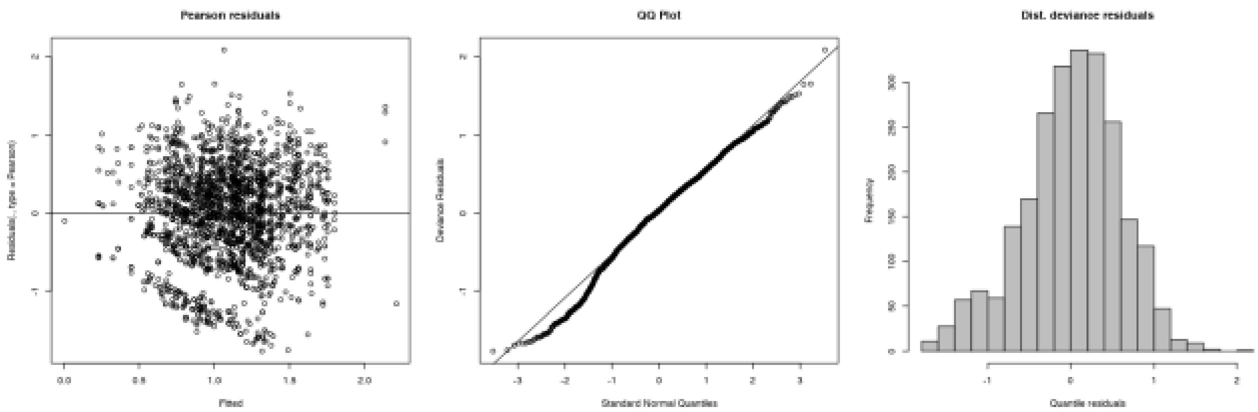

Figure 4. Residual analysis of lognormal GLMM Mod 1 selected for blue shark CPUE standardization including the covariates selected by the backward-stepwise model selection.

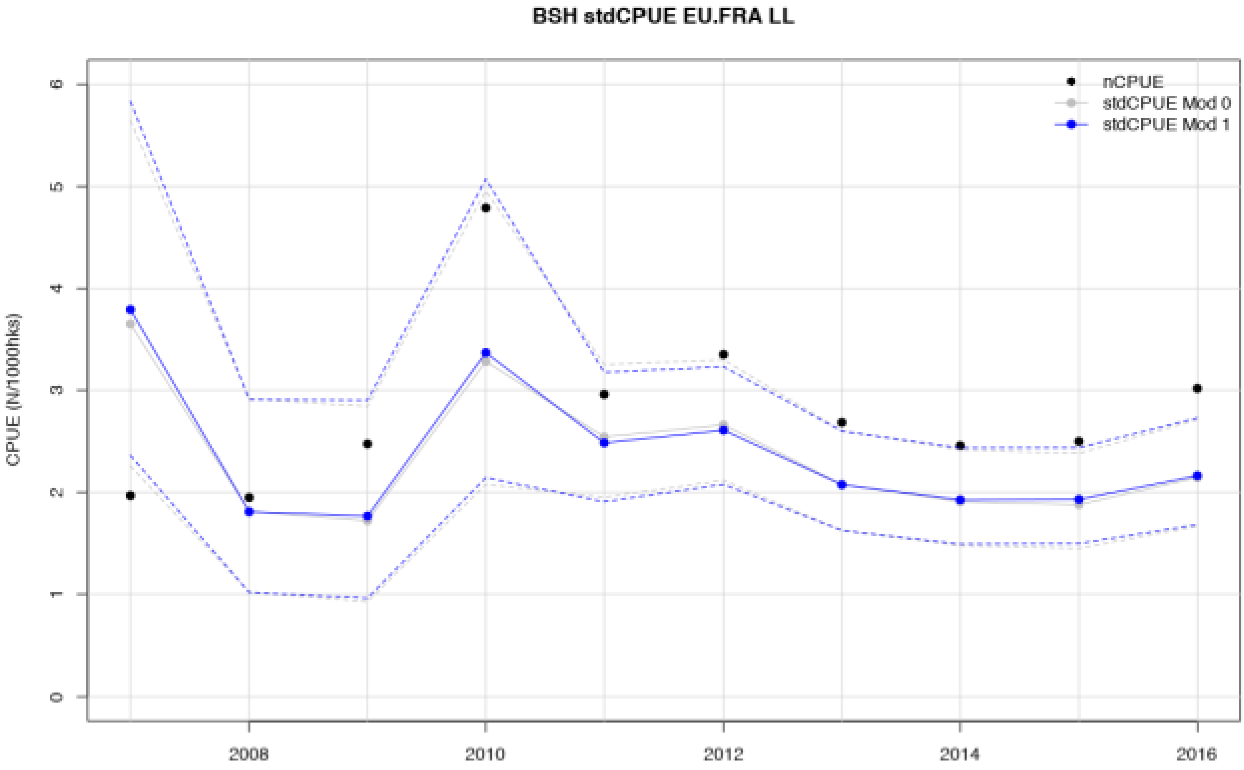

Figure 5. Nominal and standardized CPUE (N/1000 hooks) time series for Mod 0 and Mod 1 for the French longline fishery based in Reunion Island (EU.FRA LL) for the period 2007-2016.

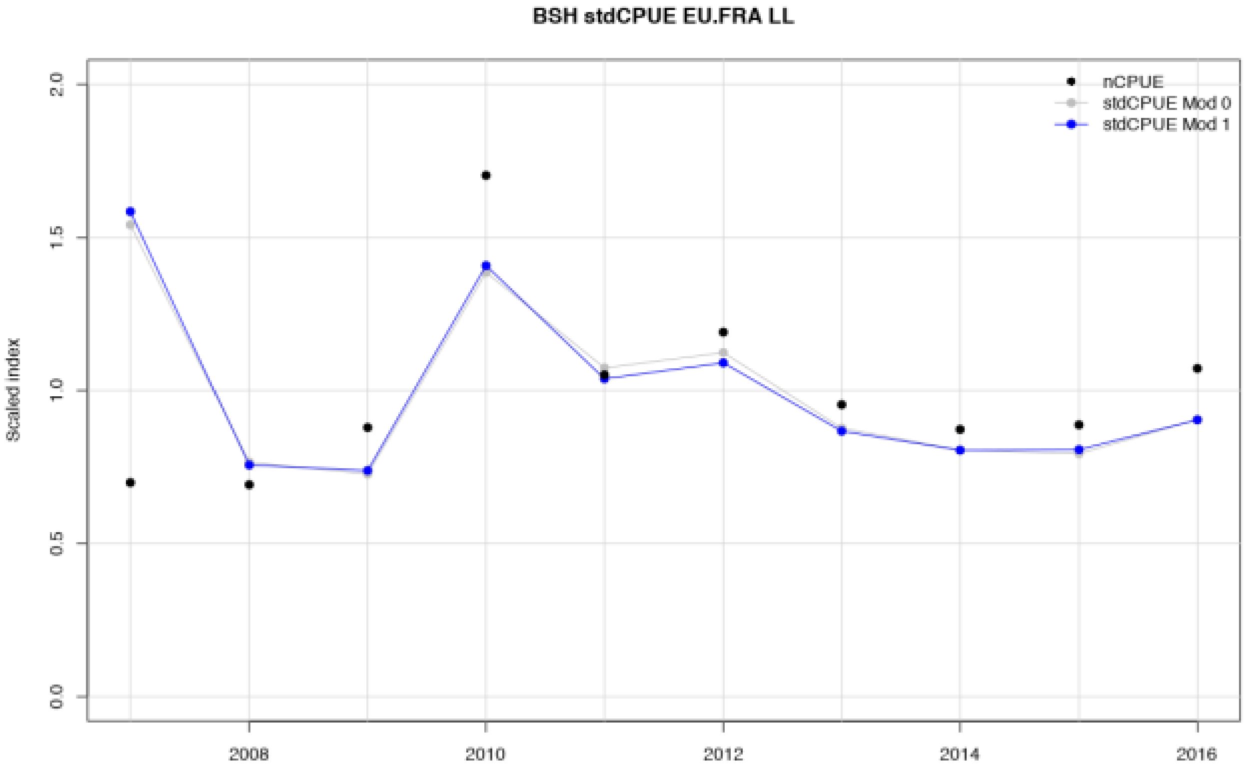

Figure 6. Nominal and standardized CPUE (scaled index by the mean) time series for Mod 0 and Mod 1 for the French longline fishery based in Reunion Island (EU.FRA LL) for the period 2007-2016.