ACCOUNTING FOR FISHING DAYS WITHOUT SET, FISHING CONCENTRATION AND PIRACY IN THE CPUE STANDARDISATION OF YELLOWFIN TUNA IN FREE SCHOOLS FOR THE EU PURSE SEINE FLEET OPERATING IN THE INDIAN OCEAN DURING THE 1991-2017 PERIOD

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SUMMARY

The time series of EU purse seine fleet catches per unit effort (CPUE) of yellowfin tuna (YFT) from the Indian Ocean were standardized using an extension of the Delta-lognormal GLMM to three components. The aim was to depict the trend in abundance for adult YFT observed in free schools (FSC). The originality of this work relied on the inclusion of i) null sets, considered as presence of YFT FSC, ii) fishing days without set, considered as absence of FSC, iii) EU fishing agreement in the exclusive economic zones driving EU purse seine fleet presence in these areas, iv) time spent by centroid cell by boat by day to constrain detectability, v) the Gulland's index of fishing effort concentration to measure the extent to which a fleet has concentrated its fishing effort in areas with higher than average catch rates and, vi) piracy as a presence absence variable. Standardized CPUE for FSC was thus defined as the product of the number of set (positive and null) by spatio-temporal strata, the proportion of sets with large YFT (>10 kg) and the catch per large YFT set. To detect strata without sets, all activities recorded in captain logbooks were used for the period 1991-2017. This new standardization approach, therefore, represents a significant advance over previous efforts, though there are a number of avenues for future progress.

KEYWORDS: Abundance; CPUE standardization; Purse seiner; Spatial variations; Logbooks; Yellowfin tuna

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1. Introduction

The goal of this paper is to develop yellowfin tuna (YFT, *Thunnus albacares*) indices of abundance derived from reported catches of EU tropical tuna purse seiners operating in the Indian Ocean, as part of the EASME/EMFF/2016/008/SC14. This work thus aimed at developing standardised Catch per unit effort (CPUE) time series to be provided to IOCT as an input for the stock assessment of YFT. In this study we considered only sets of adult YFT (> 10 kg) on free schools (FSC) so as to capture the spawning-stock biomass of the population.

Interpreting changes over time in CPUE series as a trend in abundance has always been a major challenge for scientists working in stock assessment. In the case of the tropical tuna purse seiner fishery operating in the Indian Ocean, there are several factors affecting the CPUE-abundance relationship, such as the increase in individual fishing power of the vessel due to the implementation of new technologies (Gaertner and Pallares, 2002, Fonteneau *et al*., 1999), the change in the fishing grounds, or the extensive development of fishing on drifting fish aggregative devices in the early 1990s (Hallier and Parajua, 1992), the Somali piracy issue that increased since the early 1990s within the Gulf of Aden and progressively expanded toward the east of the Indian Ocean (Chassot *et al*. 2010) and the high variability in fishing effort concentration due to anomalies in the distribution of tuna resources (Fonteneau *et al*. 2008, Potier *et al*. 2004). In addition, as tunas are usually spatially structured in schools and in clusters of schools, it is important to consider that any change in abundance may be influenced by the number (or density) of schools at sea, as well as by the size of individual schools (Laurec et Le Guen, 1977; Fréon and Misund, 1999). To account for the presence of a large number of zero-catch fishing days, the delta-lognormal method (Lo *et al*., 1992) has commonly been used in a variety of fisheries, the specific index for a given year being the product of year average fitted values of the lognormal (for the positive CPUEs) and the binomial (for the proportion of days with catch) models.

With these considerations in mind, Katara *et al*. (2016, 2017) developed a delta-lognormal GLMM approach with two sub-models: a binomial GLMM that standardises the probability of a positive set, and a lognormal GLMM that standardises catch conditional on the set being positive. In this approach, a positive set is taken to be a set with catch of the target species, so null sets are implicitly taken to indicate the absence of fish. However, bearing in mind the fact that null sets generally correspond to the presence of a fish school that simply avoided the net and that the abundance of large YFT may also be related to the number of free schools detected per unit of search time, we used in this paper a new modelling approach adopted for the Atlantic YFT stock assessment (Guéry *et al*. 2019) based on a Delta-lognormal GLMM with 3 components: (i) a Poisson first component modelling the density of free schools based on the number of sets (positive and null) per unit of single-boat searching time, (ii) a binomial second component modelling the presence of large YFT in free school positive sets (i.e., sets with catch of any species; non-null sets), and (iii) a lognormal third component modelling the amount of large YFT per free school positive set with large YFT. Along with the commonly used covariates related to vessel characteristics and spatiotemporal variability, the originality of this work consists of the inclusion of i) null sets, considered as presence of YFT FSC, ii) fishing days without sets, considered as absence of FSC, iii) data on EU fishing agreements (or lack thereof) in exclusive economic zones of regional countries driving EU purse seine fleet presence in these areas, iv) search time spent by centroid cell by boat by day to constrain detectability, v) the Gulland's index (Gulland 1956, Fonteneau 1982, Gaertner 1984, Hoyle *et al*. 2017) of fishing effort concentration to measure the extent to which a fleet has concentrated its fishing effort in areas with higher than average catch rates and, vi) piracy as a presence/absence variable. Standardized CPUE for FSC was thus defined as the product of the number of sets (positive and null) per unit search time, the proportion of positive (non-null) sets containing large YFT (> 10 kg) and the catch per set of large YFT. To detect and include cells explored, but for which a set was not carried out, all activities recorded in the captain logbooks were used for the period 1991-2017.

2. Material and Methods

2.1. Conventional fishing data

Logbook data for the French and Spanish purse seine fleets targeting tropical tuna in the Indian Ocean from 1991 to 2017 were analysed to derive the standardised CPUEs. The logbook databases are managed by the Tuna Observatory (Ob7) and the IEO for the French and the Spanish fleets, respectively. The raw logbook data (Level 0) produced by the skippers were corrected in terms of total catch per set (to account for the difference between

reported catch at sea and landed catch) and species composition (based on port size sampling and the T3 methodology – see Pallarès and Hallier 1997) to generate the Level 1 logbook database used in this paper.
The free-school sets (FSC) dataset, i.e. non-associated school sets and whales' sets, was used to derive CPUE for the adult fraction of the YFT stock, by selecting the commercial size categories 2 and 3 (> 10 kg).
The analysis was restricted to:

- The period 1991-2017 for FSC sets to be able to have the larger coverage of days without set reported
- 2018 was removed from the analyses due to a change in fishing strategy where FSC were not targeted
- The area defined by all grid cells where YFT of category 2 and 3 were fished for at least 5 years over a period of no less than 15 years, to avoid areas that are not routinely fished
- High seas and all EEZs
- Vessels with fewer activities than the 5% of the left hand distribution based on the cumulative number of days per boat (all activities confounded) were removed
- Entire days with at least one activity with problematic operations were removed
- All sets per boat and day were aggregated and attributed to the centroid of these set activities
- Distances between successive sets null-FSC/next-FSC for a boat is not significantly different from all other combinations: no need of buffer avoiding to count the same school several times
- Total number of sets per day per boat was filtered and days with unrealistic data were removed

2.2. Modelling approach: Delta-lognormal GLMMs

As mentioned in the Introduction section, delta-lognormal GLMMs were developed including three sub-models: a Poisson GLMM that standardises the number of positive and negative sets, a binomial GLMM that takes into account the fraction of positive sets with large YFT and a lognormal LMM to describe the catch conditional to positive set. Available variables are detailed in **Table 1**.

Table 1. Available variables for the calculation of CPUE and the development of the standardisation models

Variable	Description
Fleet country	France; Spain
Numbat	Unique vessel identifier
Vessel storage capacity	In m^3
Gulland's index of fishing effort concentration	Measure the extent to which a fleet has concentrated its fishing effort in areas with higher than average catch rate (Gulland 1956, Fonteneau 1981, Gaertner 1984, Hoyle *et al*. 2017)
Number of sets on FOBs	Monthly resolution per grid cell
Number of positive set	Number of positive sets per boat per day per centroid
Year	Year at which the fishing set took place
Quarter	Quarter of years
Age of vessel	Year – Year of vessel service
Economic Exclusive Zone	Identifiers of EEZs and the offshore area
Fishing access	EU fishing agreement in the different EEZ. Binary variable by cell.
Piracy	Presence/absence of piracy per cell
Searching centroid	Single-boat searching time in hours calculated as (sun set time – sun rise time) – (number of set*median of setting time)

We performed the Poisson GLMM where the full model included the following fixed effects: fleet country, age of the vessel, number of sets on FOB, vessel storage capacity, year, quarter, Gulland index and piracy variable. The number of FOB sets per trip was included as a proxy for vessels' fishing strategy changes across time due to the increase of dFADs. The random structure of the model includes fishing access and a vessel unique identifier. The time spent by single-boat searching centroid by day was calculated as (sun set time – sun rise time) – (number of set*median of setting time) and was used as an offset.

Component 1:
num_sets_fsc ~ fleet country + age of the vessel + num_sets_fob + vessel storage capacity + year + quarter + gulland index + piracy + (1| numbat) + (1|eez:fishing_access) + offset (searching_centroid)

The full model for the binomial GLMM and the lognormal LMM included the following fixed effects: fleet country, vessel storage capacity, year, quarter, Gulland index. The random structure of these models included a vessel unique identifier. The number of positive sets was used as an offset, as data were aggregated by boat, day and centroid cell.

Component 2:
yft_pos ~ fleet country + vessel storage capacity + year + quarter + gulland index + (1 | numbat) + offset(nb of positive sets)

Component 3:
log_capture ~ fleet country + vessel storage capacity + year + quarter + gulland index + (1|numbat) + offset(nb of positive sets)

GLMM tables and results are presented in appendices.

3. Results

3.1. FSC sets (1991-2017 period): Poisson GLMM (number of large-size YFT catch > 0 and = 0)

3.1.1. Diagnostics

Diagnostics are presented below (Figure 1, Figure 2, **Erreur ! Source du renvoi introuvable.**Figure 3).

Figure 1. FSC sets - number of large-size YFT catch > 0 and = 0: box-plots of residuals by year

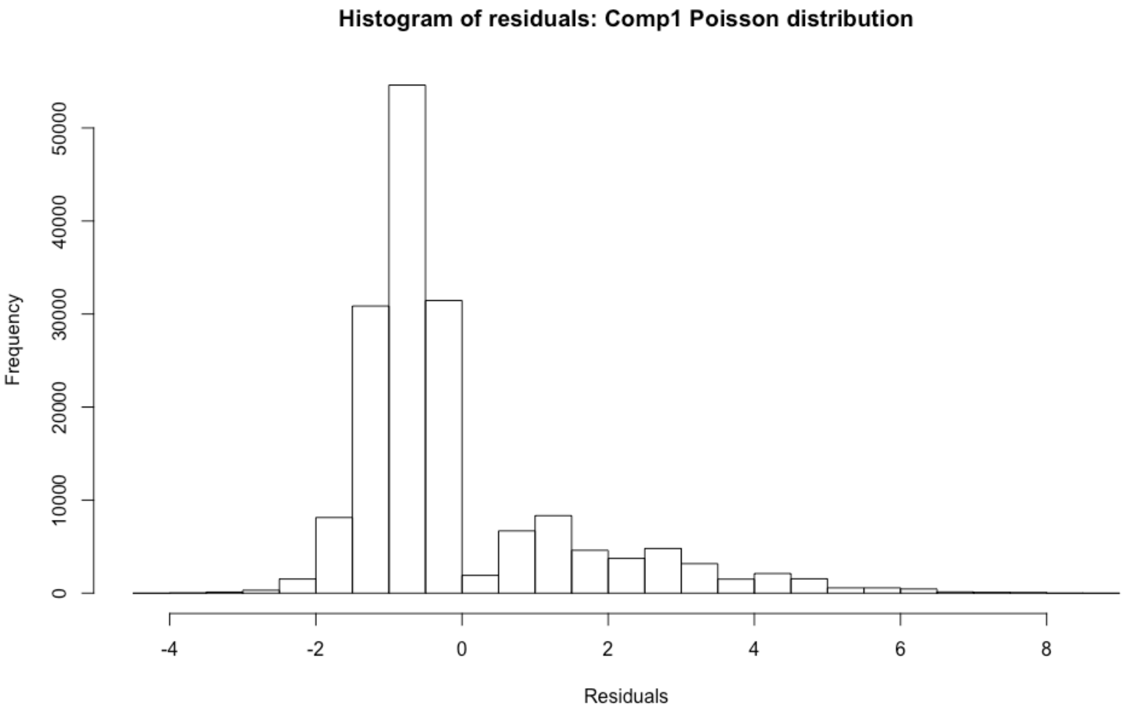

Figure 2. FSC sets – number of large-size YFT catch > 0 and = 0: histogram of residuals

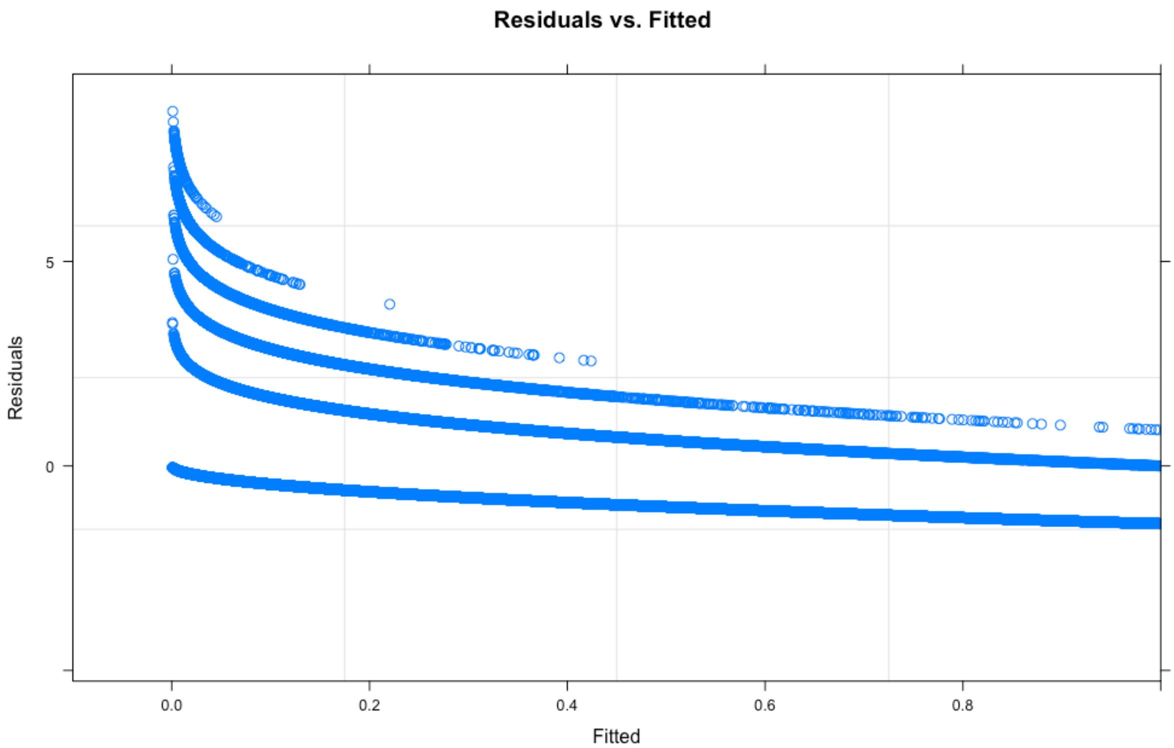

Figure 3. FSC sets – number of large-size YFT catch > 0 and = 0: residuals versus fitted

3.1.2. Standardized time series

Standardized time series are presented by year-quarter (Figure 4) and by year (Figure 5).
We used the package *arm v1.10-1* (*sim* and *fitted* functions) to simulate posterior distributions and calculate confidence intervals.

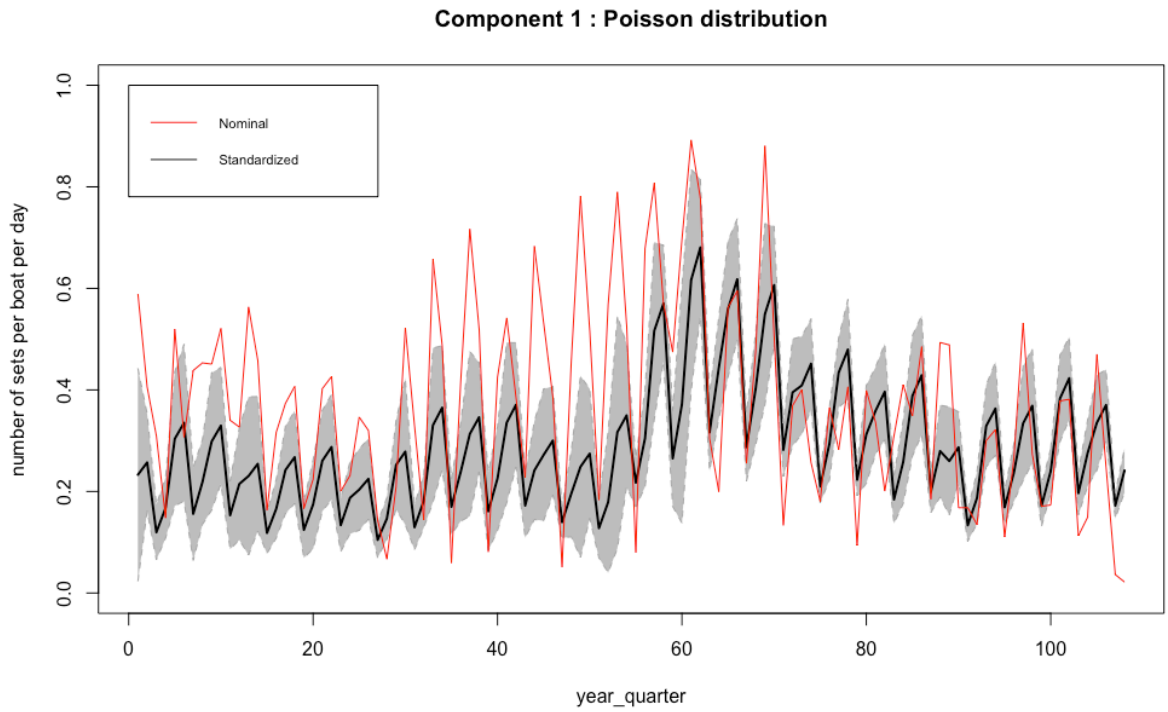

Figure 4. FSC sets – predicted number of large-size YFT catch > 0 and = 0: standardised time series by year-quarter (black) with 97.5% confidence intervals (grey) compared to nominal (red)

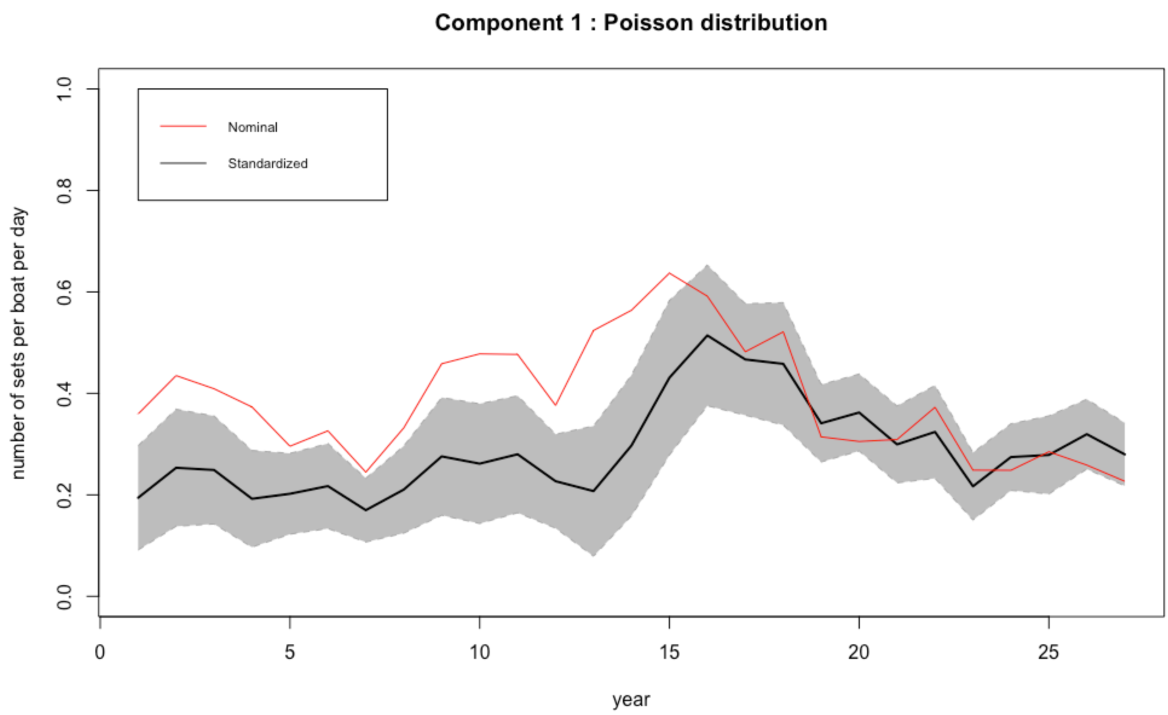

Figure 5. FSC sets – predicted number of large-size YFT catch > 0 and = 0: standardised time series by year (black) with 97.5% confidence intervals (grey) compared to nominal (red)

3.2. FSC sets (1991-2017 period): Binomial GLMM (fraction of positive set with large YFT)

3.2.1. Diagnostics

Diagnostics are presented below (Figure 6, Figure 7, Figure 8).

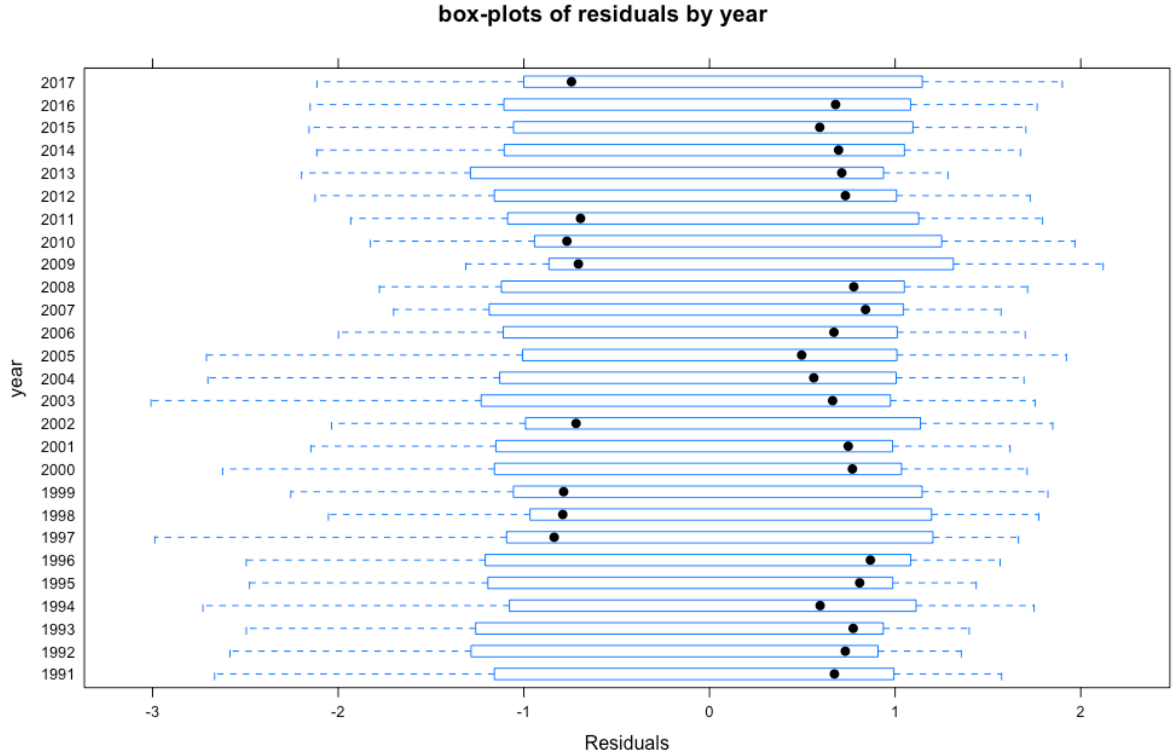

Figure 6. FSC sets - fraction of positive set with large YFT: box-plots of residuals by year

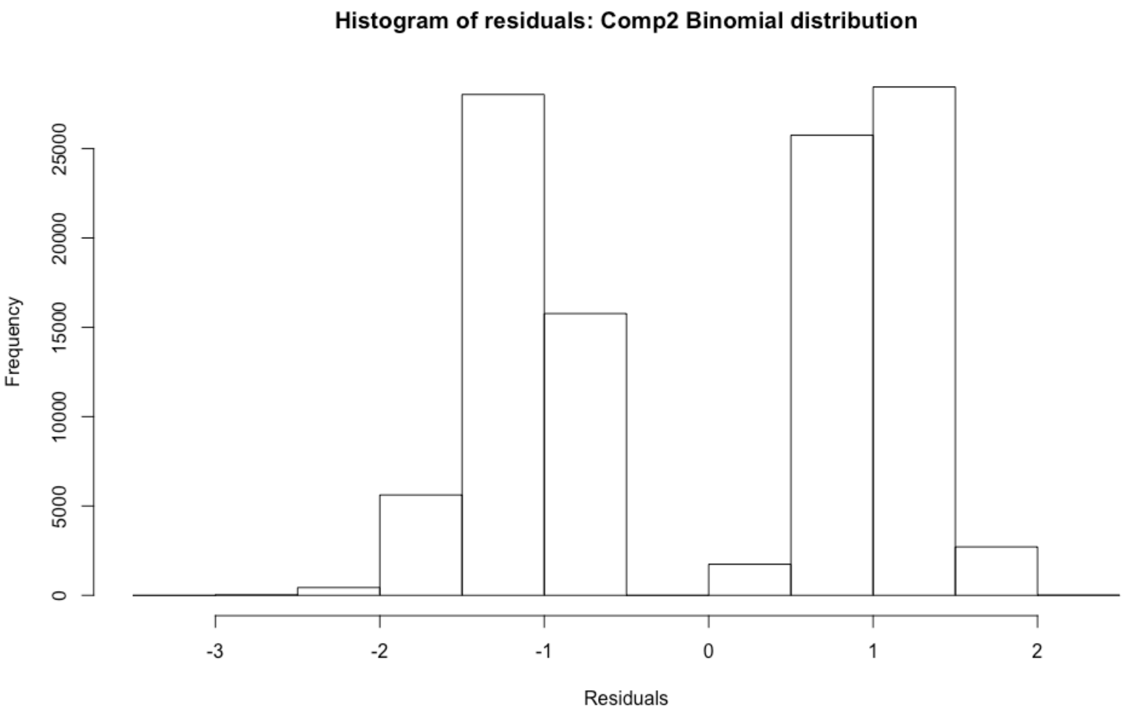

Figure 7. FSC sets – fraction of positive set with large YFT: histogram of residuals

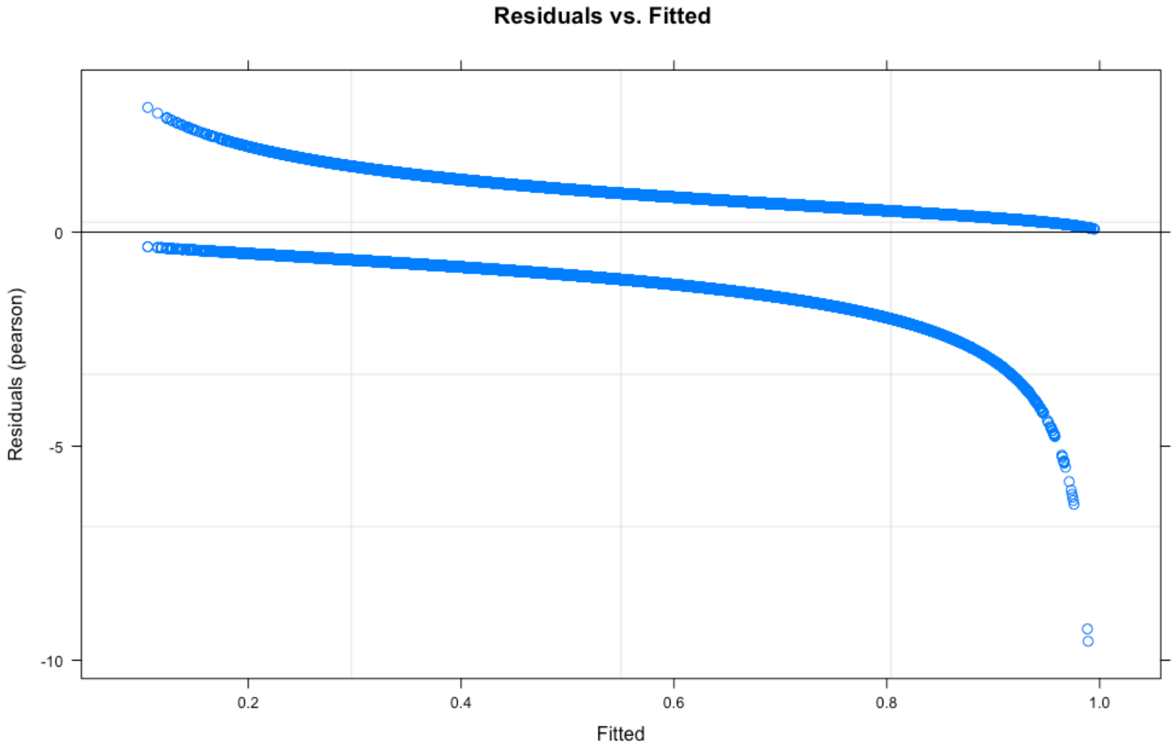

Figure 8. FSC sets – fraction of positive set with large YFT: residuals versus fitted

3.2.2. Standardized time series

Standardized time series are presented by year-quarter (Figure 9) and by year (Figure 10).
We used the package *arm v1.10-1* (*sim* and *fitted* functions) to simulate posterior distributions and calculate confidence intervals.

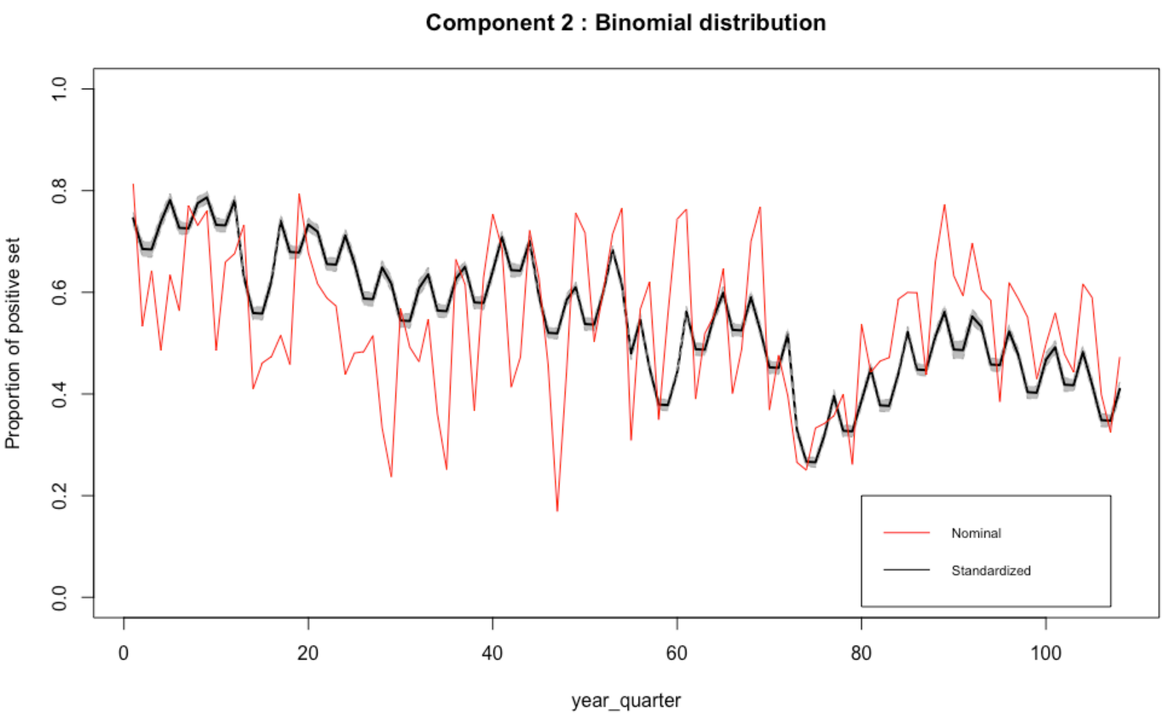

Figure 9. FSC sets – fraction of positive set with large YFT: standardised time series by year-quarter (black) with 97.5% confidence intervals (grey) compared to nominal (red)

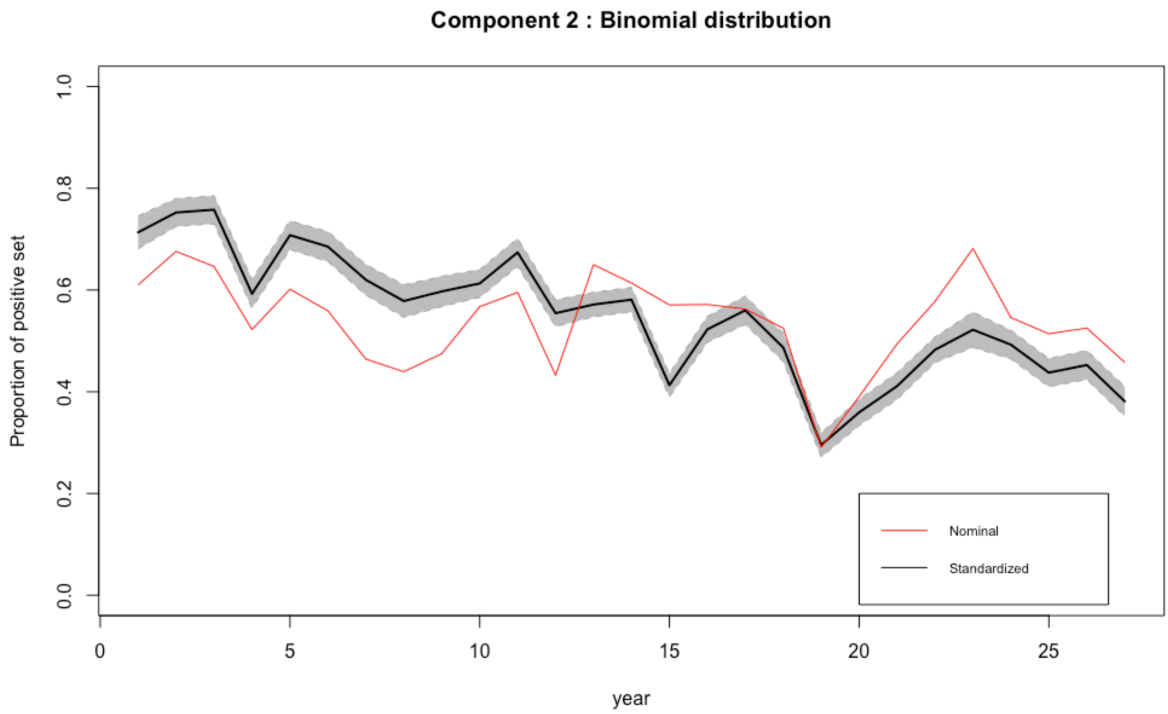

Figure 10. FSC sets – fraction of positive set with large YFT: standardised time series by year (black) with 97.5% confidence intervals (grey) compared to nominal (red)

3.3. Log-Normal GLMM (catch per hour conditional to YFT catch > 0)

3.3.1. Diagnostics

Diagnostics are presented below (Figure 11, Figure 12, Figure 13).

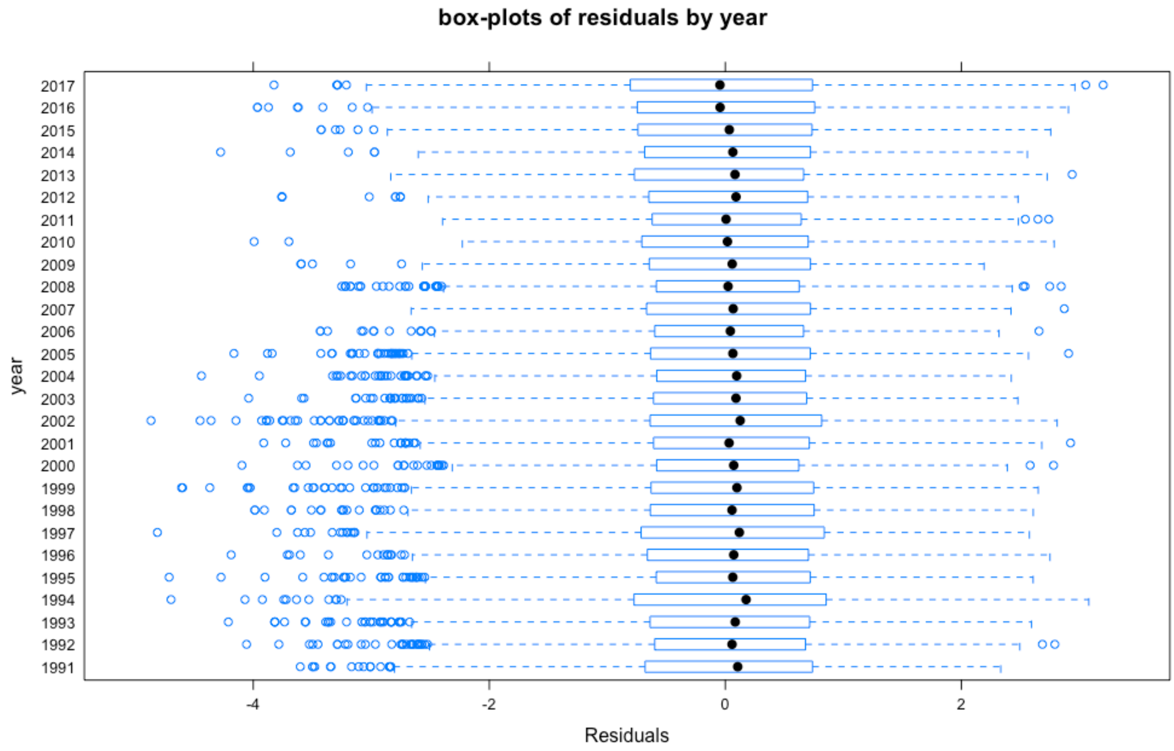

Figure 11. FSC sets – catch | catch > 0 with large YFT: box-plots of residuals by year

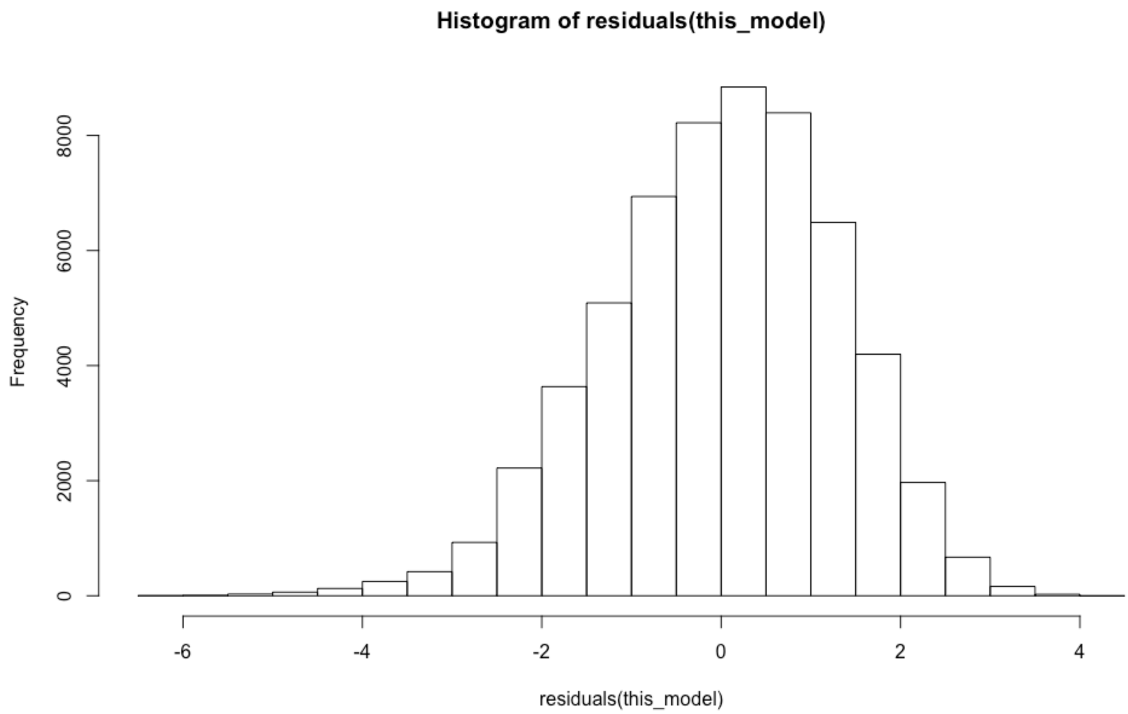

Figure 12. FSC sets – catch | catch > 0 with large YFT: histogram of residuals

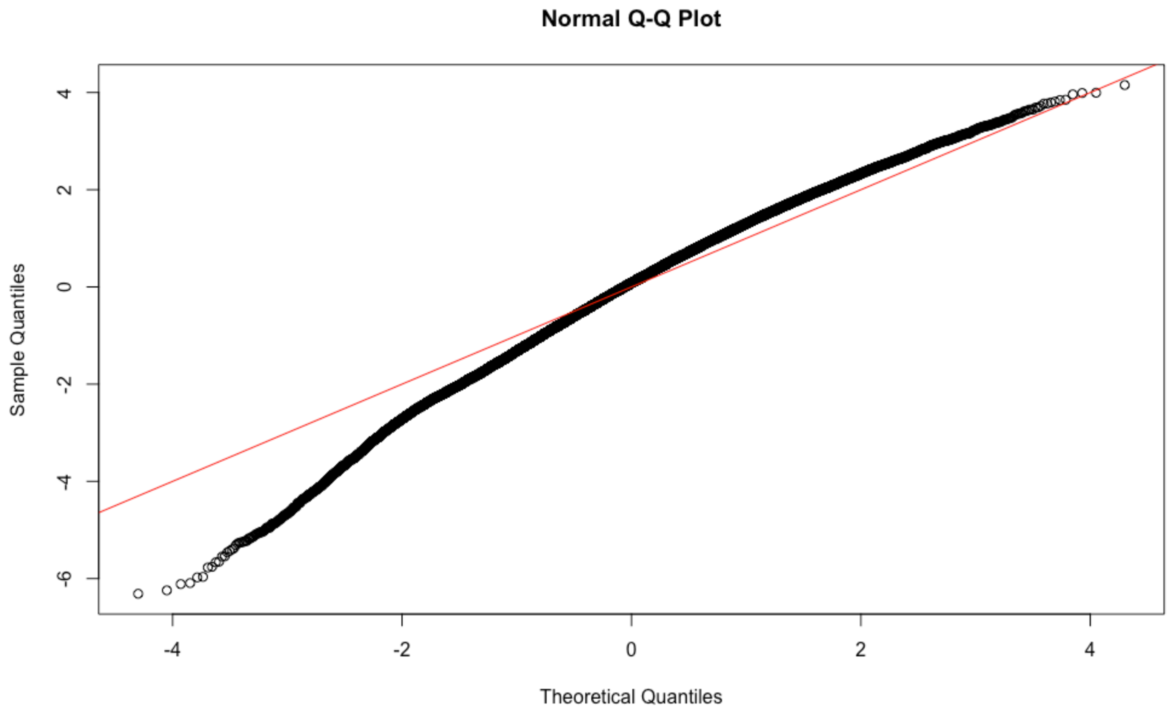

Figure 13. FSC sets – catch | catch > 0 with large YFT: normal Q-Q plot

3.3.2. Standardized time series

Standardized time series are presented by year-quarter (Figure 14) and by year (Figure 15).
We used the package *arm v1.10-1* (*sim* and *fitted* functions) to simulate posterior distributions and calculate confidence intervals.

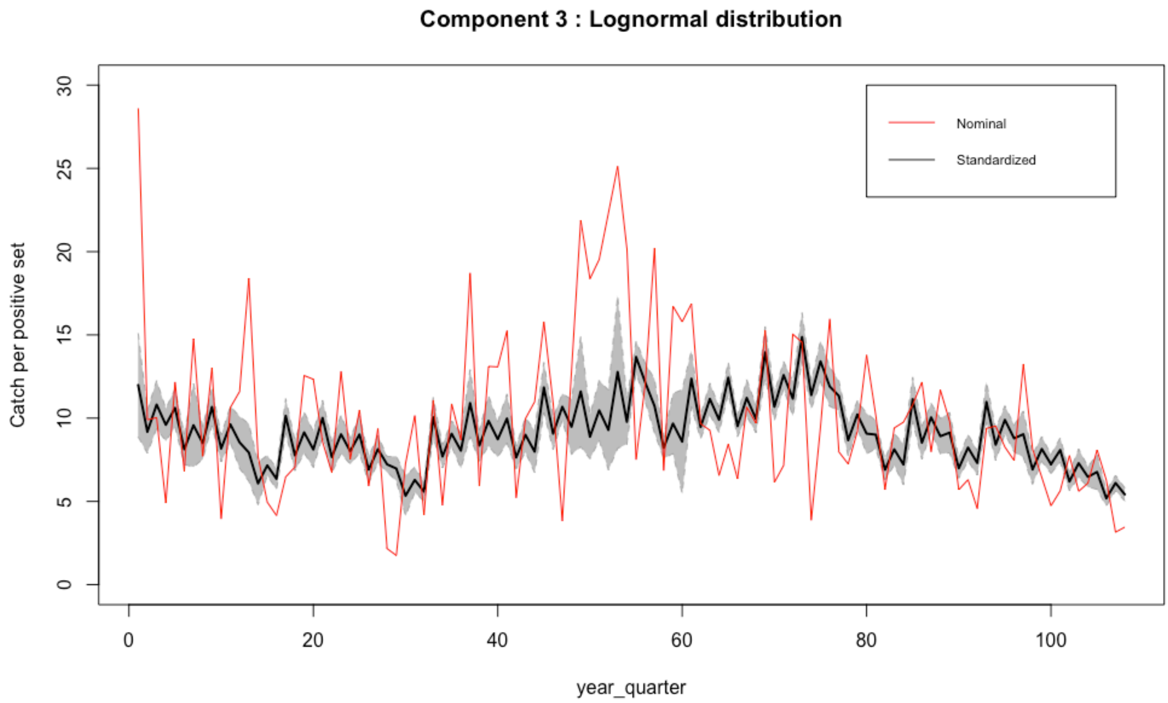

Figure 14. FSC sets – catch | catch > 0 with large YFT: standardised time series by year-quarter (black) with 97.5% confidence intervals (grey) compared to nominal (red)

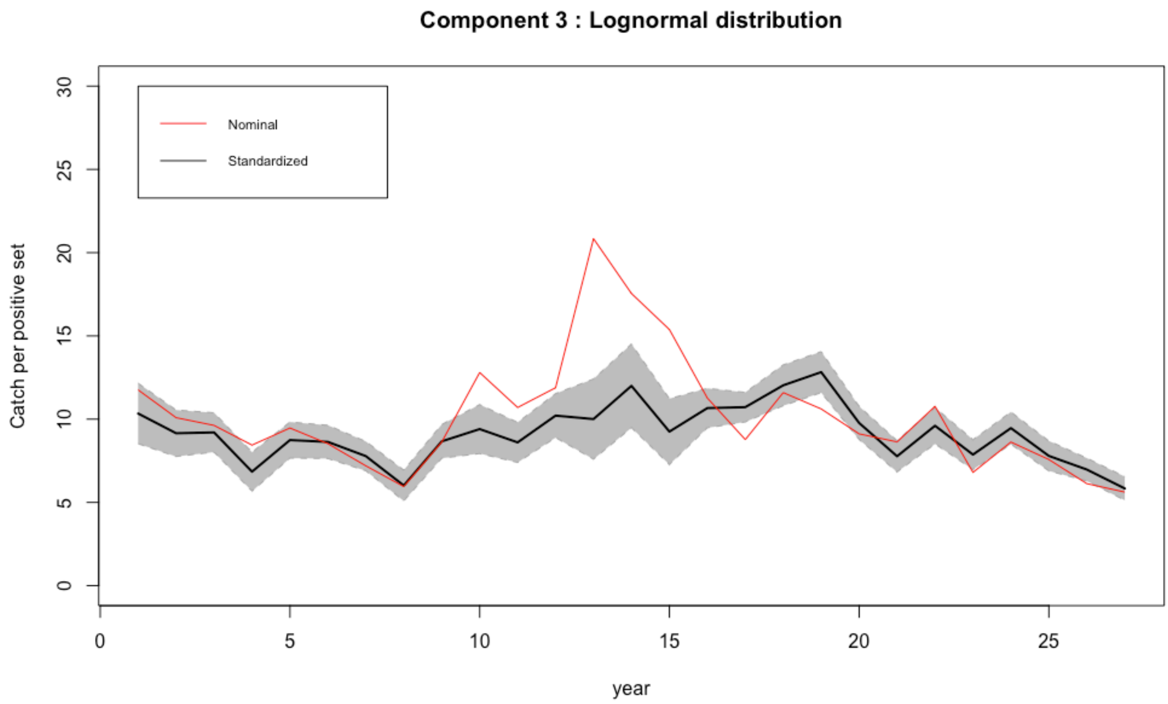

Figure 15. FSC sets – catch | catch > 0 with large YFT: standardised time series by year (black) with 97.5% confidence intervals (grey) compared to nominal (red)

3.4. Delta lognormal GLMM approach

The product of the three sub-models described above provided the standardised CPUE time series for free school sets by quarter (Figure 16) and by year (Figure 17). We considered the three components independent and calculate confidence intervals with:

$$\mathrm{Var}(XY) = E(X^2Y^2) - (E(XY))^2 = \mathrm{Var}(X)\mathrm{Var}(Y) + \mathrm{Var}(X)(E(Y))^2 + \mathrm{Var}(Y)(E(X))^2$$

The formula was first applied to the product of the first (C1) and the second component (C2) then to the product of C1*C2 and the third component.

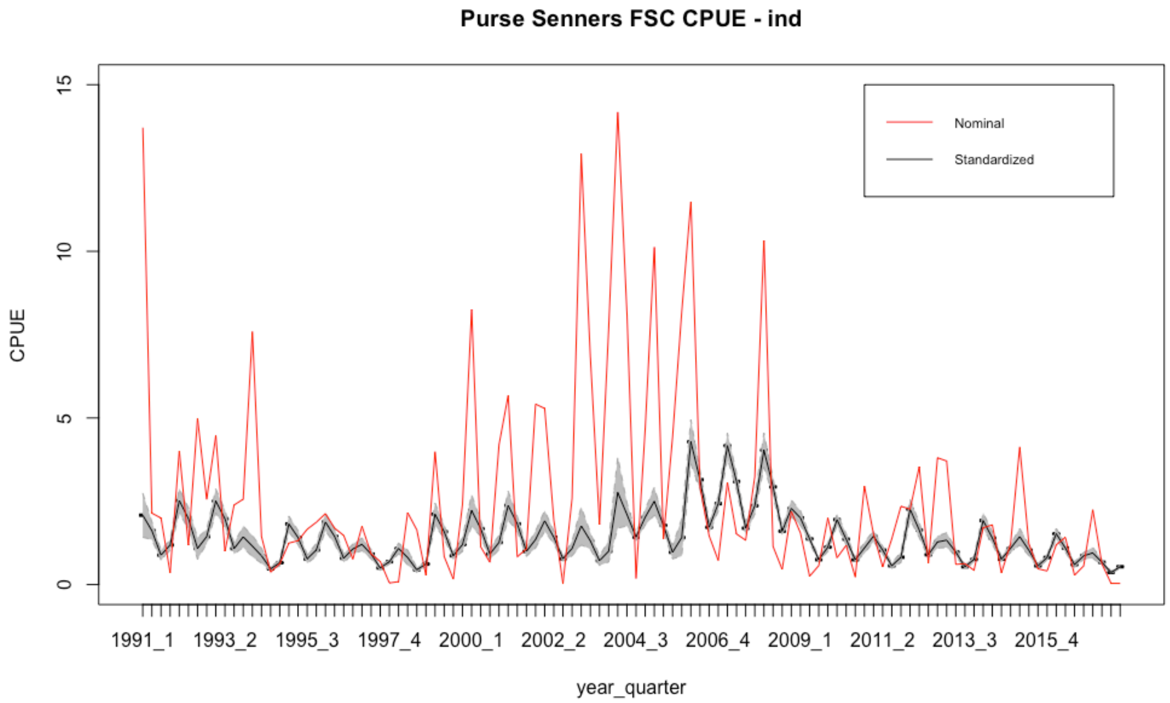

Figure 16. Standardised CPUE for free school sets of yellowfin tuna category 2 & 3 (black line), with 97.5% CIs (grey,) and compared to nominal CPUE (red). Time series on a quarter basis.

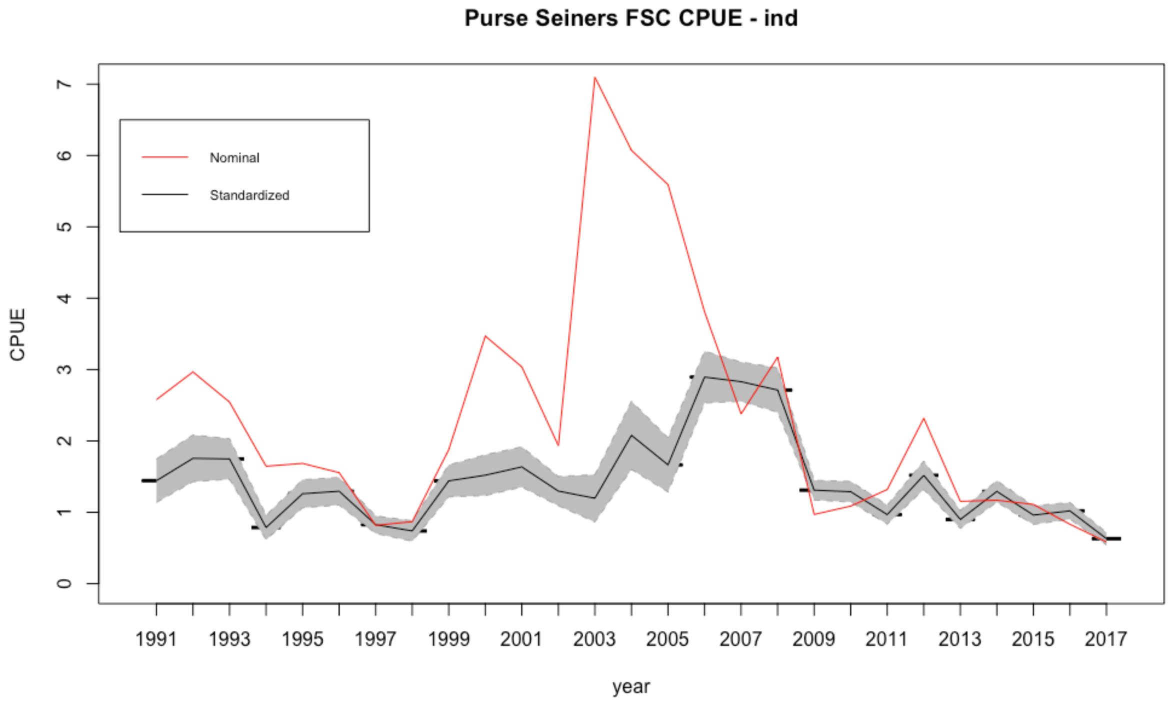

Figure 17. Standardised CPUE for free school sets of yellowfin tuna category 2 & 3 (black line), with 97.5% CIs (grey,) and compared to nominal CPUE (red). Time series on an annual basis.

4. Discussion

In this paper we used the new approach developed in the Atlantic (Guéry *et al*. SCRS/2019/066_Rev) for CPUE standardization for the tropical tuna purse seine fisheries to account for the hierarchical structure of the tuna free schools, for the non-randomised sampling and the numerous candidate variables linked to technological developments and evolving fishing strategies. A step forward compared to previous years was the inclusion of i) null sets, considered as presence of YFT FSC, ii) fishing days without set, considered as absence of FSC, iii) EU fishing agreement in the exclusive economic zones driving EU purse seine fleet presence in these areas, iv) time spent by centroid cell by boat by day to constrain detectability, v) the Gulland's index of fishing effort concentration to measure the extent to which a fleet has concentrated its fishing effort in areas with higher than average catch rates and, vi) piracy as a presence absence variable.

Despite the significant improvements in this analysis with respect to prior work, there are a number of different avenues for further improvement. Among the most interesting and pressing is the inclusion of environmental covariates. Environmental variability is undoubtedly a strong driver of tropical tuna fisheries, and, therefore, the inclusion of environmental covariates in our models is desirable. Nevertheless, this is challenging because it is often not clear if an environmental covariate primarily drives abundance (and therefore should vary when predicting standardized CPUE values) or is simply impacting catchability (and therefore should be fixed at a standard value when making predictions). For example, mixed layer depth undoubtedly impacts primary production, which ultimately impacts tuna stock size, but it also, influences the depth distribution of tunas and therefore their accessibility to surface purse-seine gear. One potential approach to resolving this issue is to split environmental variability into long-term climatological variability and short-term anomalies, the first being associated with overall abundance in the area and the second being associated with short-term changes in catchability.

5. Acknowledgements

This study was co-funded by the EU project Safewater 2 (EASME/EMFF/2016/008) Specific Contract 9 (CECOFAD2) and Specific Contract 14.

6. References

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APPENDICES

DATA PER YEAR-QUARTER

Year_quarter	Stand CPUE	Lower stand CPUE (CI97.5)	Upper stand CPUE (CI97.5)	SE CPUE	SD	CV (%)
1991_1	2,081687909	1,419722686	2,743653131	0,295520189	9,624375231	4,623351652
1991_2	1,617407446	1,349332758	1,885482133	0,1196762	3,515804089	2,173728147
1991_3	0,884662727	0,737763089	1,031562364	0,065580195	2,162833251	2,444811097
1991_4	1,187705031	1,031795114	1,343614948	0,069602642	2,238524764	1,884748069
1992_1	2,519989454	2,157028981	2,882949927	0,162035925	6,14037289	2,436666107
1992_2	1,980658195	1,658652244	2,302664146	0,143752657	4,937995742	2,49310848
1992_3	1,083553671	0,762902791	1,404204551	0,143147714	4,57246726	4,219880733
1992_4	1,439704922	1,225557786	1,653852058	0,0956014	3,429304316	2,381949427
1993_1	2,50620358	2,144595206	2,867811954	0,16143231	6,339471741	2,529511885
1993_2	1,973023239	1,715036612	2,231009865	0,115172601	3,98429078	2,019383605
1993_3	1,079405937	0,915595417	1,243216456	0,073129696	2,712960221	2,513382713
1993_4	1,432097411	1,115314585	1,748880238	0,141420905	4,94147643	3,450516977
1994_1	1,153876512	0,832096504	1,475656519	0,143651789	5,126251331	4,442634267
1994_2	0,864921689	0,640360369	1,089483009	0,100250589	3,075024824	3,555263861
1994_3	0,472807174	0,413246485	0,532367864	0,026589594	0,926217088	1,958974268
1994_4	0,655545574	0,562300011	0,748791138	0,041627484	1,515587179	2,311947847
1995_1	1,818881595	1,582964343	2,054798847	0,105320202	3,965918079	2,180415751
1995_2	1,410878157	1,20201214	1,619744174	0,093243758	3,171711724	2,248040845
1995_3	0,77167783	0,639165841	0,90418982	0,059157138	2,269876614	2,941482214
1995_4	1,037560437	0,846205645	1,228915229	0,085426246	3,046972588	2,936669979
1996_1	1,875611016	1,617372631	2,133849402	0,115284994	4,374821122	2,332477834
1996_2	1,445171205	1,220123192	1,670219217	0,100467863	3,493154951	2,417121888
1996_3	0,79034799	0,664535717	0,916160263	0,056166193	1,770847159	2,240591717
1996_4	1,069080875	0,921107486	1,217054263	0,066059548	2,136425123	1,99837559
1997_1	1,207360357	1,01763862	1,397082093	0,084697204	3,210653533	2,659233853
1997_2	0,912446311	0,77496914	1,049923482	0,061373737	2,183846485	2,393397242
1997_3	0,498851185	0,432735517	0,564966853	0,029515923	0,943826715	1,892000548
1997_4	0,686605391	0,617319672	0,75589111	0,030931125	0,910838474	1,326582177
1998_1	1,085133362	0,929046966	1,241219758	0,069681427	1,659891168	1,529665594
1998_2	0,809933554	0,584240031	1,035627076	0,100756037	2,794086521	3,449772525
1998_3	0,442718277	0,373394978	0,512041575	0,030947901	0,859229284	1,940803734
1998_4	0,616173633	0,531603669	0,700743597	0,037754448	0,732173157	1,188257852
1999_1	2,110563877	1,775406028	2,445721727	0,14962404	5,257677735	2,491124667
1999_2	1,584209791	1,385735988	1,782683594	0,088604376	2,747254937	1,734148439
1999_3	0,86602296	0,765473438	0,966572482	0,044888179	1,021088789	1,179055101
1999_4	1,199261649	0,996952659	1,401570639	0,090316514	2,349551884	1,959165363
2000_1	2,223177582	1,743744438	2,702610727	0,214032654	6,763521238	3,042276646
2000_2	1,676523517	1,448029351	1,905017684	0,102006325	2,811827922	1,677177739
2000_3	0,916554823	0,743889555	1,089220091	0,077082709	1,871126628	2,041478132
2000_4	1,263957462	1,053835477	1,474079448	0,093804458	2,644895868	2,09255133
2001_1	2,372632776	1,939416748	2,805848804	0,193400013	6,266149392	2,641011056
2001_2	1,821966379	1,595329215	2,048603543	0,101177305	3,063089161	1,681199608
2001_3	0,996358434	0,850219086	1,142497782	0,06524078	1,614492321	1,62039309
2001_4	1,351840625	1,096361362	1,607319888	0,114053242	3,55535906	2,630013475
2002_1	1,911739522	1,603213847	2,220265197	0,137734676	4,382268938	2,292293949
2002_2	1,416817368	1,224435091	1,609199645	0,085884945	2,602033243	1,836533982
2002_3	0,774361218	0,705027882	0,843694553	0,030952382	0,679730329	0,877794901
2002_4	1,084612864	0,865606195	1,303619533	0,097770834	2,619652991	2,415288512
2003_1	1,760254522	1,191350174	2,32915887	0,253975155	7,88298904	4,478323414
2003_2	1,311165091	1,065568212	1,55676197	0,109641464	3,02376717	2,306168149

2003_3	0,7166738	0,573557772	0,859789827	0,063891084	1,587001979	2,214399326
2003_4	0,999282689	0,681808036	1,316757342	0,141729756	4,250131973	4,253182827
2004_1	2,764170285	1,694769686	3,833570884	0,477410982	15,51236731	5,611943444
2004_2	2,105706012	1,757082254	2,45432977	0,155635606	4,586096001	2,177937459
2004_3	1,426336623	1,309635411	1,543037836	0,052098756	1,118246004	0,783998662
2004_4	2,018639969	1,786922095	2,250357844	0,10344548	3,228959033	1,599571535
2005_1	2,50056635	2,079211111	2,921921588	0,188105017	6,50800013	2,602610457
2005_2	1,776504656	1,609080856	1,943928456	0,074742768	2,292162921	1,290265642
2005_3	0,970320449	0,77185176	1,168789137	0,088602093	2,853942054	2,941236638
2005_4	1,411261482	0,853094409	1,969428555	0,249181729	8,234865827	5,835109887
2006_1	4,285675095	3,625524849	4,94582534	0,294709931	11,34296663	2,646716417
2006_2	3,146182391	2,865563909	3,426800874	0,125276108	3,955106505	1,257112911
2006_3	1,719291499	1,54741582	1,891167178	0,076730214	2,355999908	1,370331854
2006_4	2,42863085	2,20075842	2,65650328	0,101728763	2,940273968	1,210671424
2007_1	4,168768695	3,792232327	4,545305064	0,168096593	6,176113081	1,481519732
2007_2	3,094794409	2,842437536	3,347151282	0,112659318	3,517199477	1,136488895
2007_3	1,691504219	1,505093272	1,877915166	0,083219173	2,3795442	1,406762202
2007_4	2,365613118	2,118522967	2,61270327	0,110308103	3,75910418	1,589061267
2008_1	4,035484713	3,523178858	4,547790568	0,228707971	8,493589567	2,104725992
2008_2	2,931151758	2,670806696	3,19149682	0,116225474	3,254724906	1,110391128
2008_3	1,601521415	1,48022409	1,72281874	0,054150591	1,250744091	0,780972442
2008_4	2,283851547	2,032419925	2,53528317	0,11224626	2,953686666	1,293291882
2009_1	1,998283529	1,783451442	2,213115616	0,095907182	2,295807579	1,148889808
2009_2	1,370731417	1,2535702	1,487892634	0,052304115	1,040035297	0,758744772
2009_3	0,748302331	0,675858014	0,820746647	0,032341213	0,576894401	0,770937598
2009_4	1,122721197	0,996242988	1,249199407	0,056463487	1,081334329	0,963137003
2010_1	1,948998723	1,780524629	2,117472817	0,075211649	1,704520465	0,874562125
2010_2	1,362754955	1,19571805	1,529791859	0,074570047	1,858141463	1,363518405
2010_3	0,744155647	0,678485679	0,809825616	0,02931695	0,480767471	0,64605768
2010_4	1,097741373	0,929280719	1,266202027	0,075205649	1,70757852	1,555538091
2011_1	1,454370692	1,292672091	1,616069293	0,072186876	1,661678666	1,142541359
2011_2	1,032735033	0,917732527	1,147737539	0,051340404	1,34653827	1,303856485
2011_3	0,564071993	0,487625231	0,640518755	0,034128019	0,930719379	1,650001047
2011_4	0,820761838	0,664341093	0,977182582	0,069830689	1,78507429	2,174899232
2012_1	2,259379117	1,952145829	2,566612404	0,137157718	3,983688765	1,763178537
2012_2	1,638979408	1,415459754	1,862499063	0,09978556	2,621777273	1,599640154
2012_3	0,895487235	0,808868331	0,982106139	0,038669153	0,961195305	1,073376892
2012_4	1,278474478	1,095381489	1,461567466	0,081737941	2,313273138	1,809401109
2013_1	1,332013456	1,111660555	1,552366357	0,098371831	1,803503196	1,3539677
2013_2	0,977643943	0,869082246	1,08620564	0,048465043	0,823217903	0,842042656
2013_3	0,534250455	0,472314608	0,596186303	0,027649932	0,434950837	0,814132834
2013_4	0,754813246	0,661218824	0,848407667	0,041783224	0,584735757	0,774676068
2014_1	1,921166864	1,686990947	2,155342781	0,10454282	3,222219369	1,677219938
2014_2	1,397770404	1,213951784	1,581589023	0,082061884	2,341421912	1,675111954
2014_3	0,76373281	0,689524949	0,83794067	0,033128509	0,903779785	1,183371689
2014_4	1,087495374	0,968311214	1,206679535	0,053207215	1,63295186	1,501571316
2015_1	1,438665659	1,188412949	1,68891837	0,11171996	3,161922106	2,197815792
2015_2	1,029700157	0,871026572	1,188373743	0,070836422	2,008916451	1,950972268
2015_3	0,562481262	0,499974834	0,624987691	0,027904656	0,792540787	1,409008336
2015_4	0,81270861	0,737166574	0,888250646	0,033724123	1,012115022	1,24536028
2016_1	1,523980724	1,359755547	1,688205901	0,073314811	2,199908767	1,443527948
2016_2	1,095642044	0,979022869	1,212261219	0,052062132	1,405443332	1,282757758
2016_3	0,598542899	0,51955404	0,677531757	0,035262883	0,947985846	1,583822726
2016_4	0,861384975	0,760662532	0,962107418	0,044965376	1,349230916	1,56635065
2017_1	0,950312295	0,785522728	1,115101862	0,073566771	2,242898121	2,360169529
2017_2	0,668788859	0,59545217	0,742125548	0,032739593	0,847799526	1,267663949
2017_3	0,365238609	0,332625938	0,397851279	0,014559228	0,340051368	0,931038944
2017_4	0,535691349	0,485464607	0,585918091	0,022422653	0,488108101	0,911174133

Data per year

Year	Stand CPUE	Lower stand CPUE (CI97.5)	Upper stand CPUE (CI97.5)	SE CPUE	SD	CV (%)
1991	1,442865778	1,13981229	1,745919266	0,135291736	8,413860294	5,831353423
1992	1,75597656	1,428717901	2,08323522	0,146097616	9,935938496	5,658354855
1993	1,747682542	1,464206308	2,031158776	0,12655189	9,033371702	5,168771495
1994	0,786787737	0,615745331	0,957830144	0,076358217	5,0897071	6,468971055
1995	1,259749505	1,06301408	1,45648493	0,087828315	6,339917189	5,032680834
1996	1,295052771	1,102033055	1,488072488	0,086169516	5,897875086	4,554158113
1997	0,826315811	0,703771658	0,948859964	0,054707211	3,672794095	4,444782548
1998	0,738489706	0,595216036	0,881763376	0,06396146	3,141743462	4,254281997
1999	1,440014569	1,216104241	1,663924898	0,099959968	5,791192712	4,021620916
2000	1,520053346	1,234536449	1,805570244	0,127462901	7,044631895	4,634463595
2001	1,635699553	1,354155536	1,91724357	0,125689293	7,320639455	4,475540413
2002	1,296882743	1,092274665	1,501490821	0,091342892	5,102260812	3,934249908
2003	1,196844025	0,865847451	1,5278406	0,147766328	8,23357736	6,879407161
2004	2,078713222	1,601499171	2,555927274	0,213041987	11,74538154	5,650313575
2005	1,664663234	1,285869937	2,043456531	0,16910415	10,51688166	6,317723274
2006	2,894944959	2,532478222	3,257411695	0,161815507	10,27554358	3,549478048
2007	2,83017011	2,554994632	3,105345589	0,122846196	7,998802034	2,826261928
2008	2,713002358	2,402211722	3,023792995	0,13874582	7,951705083	2,93096136
2009	1,310009618	1,172152542	1,447866695	0,061543338	2,495530028	1,904970767
2010	1,288412674	1,14395397	1,432871379	0,064490493	2,84768314	2,21022596
2011	0,967984889	0,83524471	1,100725068	0,059259008	2,954068795	3,051771602
2012	1,518080059	1,320042652	1,716117467	0,088409557	4,797307432	3,160114911
2013	0,899680275	0,77509726	1,02426329	0,055617418	1,80512421	2,006406343
2014	1,292541363	1,142079075	1,443003651	0,067170664	3,940898775	3,048953703
2015	0,960888922	0,830868668	1,090909177	0,058044756	3,331581936	3,467187371
2016	1,01988766	0,902673696	1,137101625	0,052327663	2,975521975	2,91749973
2017	0,630007778	0,54306679	0,716948766	0,038812941	1,926611718	3,058076084

COEFFICIENTS OF THE COMPONENT 1 (POISSON DISTRIBUTION)

Generalized linear mixed model fit by maximum likelihood (Laplace Approximation) ['glmerMod']
Family: poisson (log)
Formula: num_sets_fsc ~ pays + age + num_sets_fob + cap_m3 + yr + quarter +
Gulland + Piracy + (1 | c_bat) + (1 | eez_iso_3digit:fishing_access) +
offset(searching_centroid)
Data: D

AIC	BIC	logLik	deviance	df.resid
491771.0	492152.1	-245847.5	491695.0	167301

Scaled residuals:

Min	1Q	Median	3Q	Max
-3.077	-0.701	-0.426	-0.109	158.277

Random effects:

Groups	Name	Variance	Std.Dev.
c_bat	(Intercept)	0.1700	0.4123
eez_iso_3digit:fishing_access	(Intercept)	0.2308	0.4804

Number of obs: 167339, groups: c_bat, 76; eez_iso_3digit:fishing_access, 10

Fixed effects:

	Estimate	Std. Error	z value	Pr(>|z|)	
(Intercept)	-1.455056611	0.189162065	-7.69211635	1.447209e-14	***
pays4	0.289983807	0.124763035	2.32427663	2.011067e-02	*
age	-0.222187130	0.041097101	-5.40639420	6.430618e-08	***
num_sets_fob	-0.122979624	0.007238805	-16.98893943	9.916604e-65	***
cap_m3	0.003323342	0.065361909	0.05084524	9.594488e-01	
yr1992	0.265508787	0.026819172	9.89996221	4.164324e-23	***
yr1993	0.248218116	0.028249811	8.78654062	1.542359e-18	***
yr1994	-0.010560520	0.031435833	-0.33593892	7.369169e-01	
yr1995	0.039581475	0.034896595	1.13425034	2.566896e-01	
yr1996	0.111869781	0.038320180	2.91934382	3.507691e-03	**
yr1997	-0.134455518	0.043473929	-3.09278507	1.982877e-03	**
yr1998	0.079818017	0.048724378	1.63815363	1.013896e-01	
yr1999	0.350331581	0.049865223	7.02556931	2.131951e-12	***
yr2000	0.297152347	0.054004444	5.50236840	3.747229e-08	***
yr2001	0.365439682	0.058196634	6.27939550	3.398920e-10	***
yr2002	0.155093612	0.063558256	2.44018044	1.467993e-02	*
yr2003	0.065441822	0.067654619	0.96729275	3.333977e-01	
yr2004	0.307892365	0.071930349	4.28042363	1.865379e-05	***
yr2005	0.506415725	0.076167260	6.64873234	2.956280e-11	***
yr2006	0.683346438	0.081111237	8.42480607	3.613482e-17	***
yr2007	0.586736362	0.086416508	6.78963289	1.124192e-11	***
yr2008	0.567980500	0.091609778	6.19999866	5.646364e-10	***
yr2009	0.272891506	0.099019257	2.75594377	5.852306e-03	**
yr2010	0.333130986	0.105585126	3.15509390	1.604465e-03	**
yr2011	0.142649914	0.108246148	1.31782901	1.875609e-01	
yr2012	0.221640568	0.112288510	1.97384904	4.839891e-02	*
yr2013	-0.180220019	0.124498505	-1.44756774	1.477380e-01	
yr2014	0.055432572	0.122238626	0.45347837	6.502043e-01	
yr2015	0.070614050	0.126958091	0.55619968	5.780744e-01	
yr2016	0.207726363	0.132482507	1.56795314	1.168921e-01	
yr2017	0.074566447	0.138618818	0.53792442	5.906292e-01	
quarter2	0.099194593	0.010623318	9.33744027	9.869115e-21	***
quarter3	-0.666818086	0.013056726	-51.07085119	0.000000e+00	***
quarter4	-0.329046120	0.011017016	-29.86708318	5.268171e-196	***
Gulland	0.343772805	0.003702762	92.84226408	0.000000e+00	***
Piracy	-0.301251457	0.032041783	-9.40183199	5.362119e-21	***

Signif. codes: 0 ‘***’ 0.001 ‘**’ 0.01 ‘*’ 0.05 ‘.’ 0.1 ‘ ’ 1

COEFFICIENTS OF THE COMPONENT 2 (BINOMIAL DISTRIBUTION)

Generalized linear mixed model fit by maximum likelihood (Laplace Approximation) ['glmerMod']
Family: binomial (logit)
Formula: yft_pos ~ pays + cap_m3 + annee_de_peche + trimestre + Gulland +
(1 | numbat) + offset(nb_de_calees_pos)
Data: D
Control: glmerControl(optimizer = "bobyqa", optCtrl = list(maxfun = 30000))

AIC	**BIC**	**logLik**	**deviance**	**df.resid**
138577.7	138903.9	-69254.9	138509.7	108523

Scaled residuals:

Min	1Q	Median	3Q	Max
-9.5558	-0.9132	0.4826	0.8547	2.9116

Random effects:

Groups	Name	Variance	Std.Dev.
numbat	(Intercept)	0.1207	0.3475

Number of obs: 108557, groups: numbat, 76

Fixed effects:

	Estimate	Std. Error	z value	Pr(>|z|)	
(Intercept)	-0.78859634	0.08063651	-9.7796436	1.376945e-22	***
pays4	-0.54628593	0.09979062	-5.4743216	4.391908e-08	***
cap_m3	0.10234305	0.05142459	1.9901577	4.657356e-02	*
annee_de_peche1992	0.19988941	0.04853933	4.1180913	3.820234e-05	***
annee_de_peche1993	0.22966532	0.04780664	4.8040460	1.554911e-06	***
annee_de_peche1994	-0.53981246	0.04792644	-11.2633552	1.990336e-29	***
annee_de_peche1995	-0.02726223	0.04635787	-0.5880821	5.564772e-01	
annee_de_peche1996	-0.13458560	0.04721599	-2.8504240	4.366099e-03	**
annee_de_peche1997	-0.42399658	0.04838378	-8.7631961	1.897911e-18	***
annee_de_peche1998	-0.59911435	0.05699020	-10.5125850	7.559265e-26	***
annee_de_peche1999	-0.52055772	0.05288527	-9.8431507	7.337622e-23	***
annee_de_peche2000	-0.45476172	0.05227425	-8.6995368	3.332416e-18	***
annee_de_peche2001	-0.18707932	0.05252919	-3.5614357	3.688324e-04	***
annee_de_peche2002	-0.69662233	0.05145806	-13.5376728	9.371097e-42	***
annee_de_peche2003	-0.62723936	0.05540503	-11.3209832	1.033067e-29	***
annee_de_peche2004	-0.30787895	0.05277719	-5.8335608	5.425682e-09	***
annee_de_peche2005	-0.72442679	0.04966080	-14.5874984	3.373423e-48	***
annee_de_peche2006	-0.27914295	0.04909777	-5.6854505	1.304683e-08	***
annee_de_peche2007	-0.12706957	0.04995947	-2.5434534	1.097627e-02	*
annee_de_peche2008	-0.42269004	0.05120268	-8.2552325	1.516068e-16	***
annee_de_peche2009	-1.24347970	0.05631289	-22.0816189	4.747731e-108	***
annee_de_peche2010	-0.95082038	0.05521889	-17.2191128	1.908918e-66	***
annee_de_peche2011	-0.73127552	0.05424321	-13.4814205	2.011954e-41	***
annee_de_peche2012	-0.44002651	0.05389472	-8.1645574	3.226158e-16	***
annee_de_peche2013	-0.28202258	0.08294983	-3.3999177	6.740613e-04	***
annee_de_peche2014	-0.40008467	0.05285174	-7.5699434	3.733868e-14	***
annee_de_peche2015	-0.62222737	0.05353587	-11.6226251	3.162667e-31	***
annee_de_peche2016	-0.56139277	0.05325504	-10.5415904	5.555139e-26	***
annee_de_peche2017	-0.85729625	0.05520764	-15.5285808	2.222442e-54	***
trimestre2	-0.29729973	0.01810809	-16.4180595	1.420371e-60	***
trimestre3	-0.30188522	0.01861215	-16.2197900	3.654421e-59	***
trimestre4	-0.03682949	0.01829317	-2.0132920	4.408392e-02	*
Gulland	0.83325468	0.01312961	63.4637790	0.000000e+00	***

Signif. codes: 0 ‘***’ 0.001 ‘**’ 0.01 ‘*’ 0.05 ‘.’ 0.1 ‘ ’ 1

COEFFICIENTS OF THE COMPONENT 3 (LOGNORMAL DISTRIBUTION)

Linear mixed model fit by REML ['lmerMod']
Formula: log_capture ~ pays + cap_m3 + annee_de_peche + trimestre + Gulland +
(1 | numbat) + offset(nb_de_calees_pos)
Data: D
Control: lmerControl(optimizer = "bobyqa", optCtrl = list(maxfun = 40000))

REML criterion at convergence: 197377.5

Scaled residuals:

Min	1Q	Median	3Q	Max
-4.8663	-0.6524	0.0623	0.7151	3.2019

Random effects:

Groups	Name	Variance	Std.Dev.
numbat	(Intercept)	0.04239	0.2059
Residual		1.68247	1.2971

Number of obs: 58671, groups: numbat, 76

Fixed effects:

	Estimate	Std. Error	t value
(Intercept)	0.86935631	0.053627721	16.2109502
pays4	0.17126462	0.061091532	2.8034101
cap_m3	0.09443620	0.031488820	2.9990389
annee_de_peche1992	-0.12161704	0.036536279	-3.3286651
annee_de_peche1993	-0.11623846	0.036896560	-3.1503873
annee_de_peche1994	-0.41223674	0.038817010	-10.6200026
annee_de_peche1995	-0.16753299	0.036462574	-4.5946562
annee_de_peche1996	-0.18012338	0.038121714	-4.7249549
annee_de_peche1997	-0.28424807	0.041003065	-6.9323614
annee_de_peche1998	-0.54173273	0.049476805	-10.9492262
annee_de_peche1999	-0.17636691	0.045120895	-3.9087637
annee_de_peche2000	-0.09470548	0.041890059	-2.2608105
annee_de_peche2001	-0.18361027	0.041501909	-4.4241403
annee_de_peche2002	-0.01220757	0.044077921	-0.2769544
annee_de_peche2003	-0.03273176	0.041608818	-0.7866544
annee_de_peche2004	0.06341697	0.040859649	1.5520684
annee_de_peche2005	-0.28229520	0.039122698	-7.2156372
annee_de_peche2006	-0.14007822	0.039184459	-3.5748411
annee_de_peche2007	-0.13488259	0.040498468	-3.3305603
annee_de_peche2008	-0.01946548	0.041875591	-0.4648407
annee_de_peche2009	0.04424476	0.052081354	0.8495317
annee_de_peche2010	-0.22770881	0.048360239	-4.7085956
annee_de_peche2011	-0.45670980	0.045077741	-10.1316036
annee_de_peche2012	-0.24491700	0.043174700	-5.6726971
annee_de_peche2013	-0.44383635	0.061122142	-7.2614660
annee_de_peche2014	-0.25974942	0.042899524	-6.0548322
annee_de_peche2015	-0.45407207	0.043895173	-10.3444646
annee_de_peche2016	-0.56494518	0.043559871	-12.9693952
annee_de_peche2017	-0.74285066	0.046196950	-16.0800803
trimestre2	-0.26714294	0.015417330	-17.3274446
trimestre3	-0.10305813	0.015617528	-6.5988760
trimestre4	-0.22261198	0.014472152	-15.3820930
Gulland	0.58171446	0.009453955	61.5313353